METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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Subscription Rates throughout the World - - 24/- per annum, Post free

Published monthly by THE KENNEDY PRESS, LIMITED.

REGISTERED OFFICE: 31, King Street West, Manchester, 3. *Telephone:* BLA 2084. *Telegrams:* "Kenpred," Manchester.

LONDON OFFICE: Bedford Street, W.C. 2. *Telephone:* Temple Bar 2629.

TN600. M58 v.37 May - Oct. 1946

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METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

MAY, 1946 VOL. XXXIV. No. 199

The British Iron and Steel Industry

The Government White Paper

WHAT the economic future of the iron and steel industry will be it is impossible at this critical time to predict; certain it is that, if manufacture in this country, with the high cost of coal and the necessity for importing so much of the necessary raw materials, is to succeed, both the equipment and the direction of our works must be of first-class quality. Thus, efficiency of the iron and steel industry is a primary consideration. This thought was apparently shared by the Government, for in May, 1945, the industry was asked, through the President of the Iron and Steel Federation, to submit, within six months, a plan, to be carried out in five years, embodying the major improvements and new construction necessary to put the industry on an efficient operating basis. It was emphasised that, in formulating the plan, priority should be given to new plant at the finishing end of the industry which would increase exports; to schemes to reduce fuel costs and consumption; and to schemes to enable a greater proportion of output to be produced by large scale production methods. The industry was also asked to supply information on the adjustments between firms which may be necessary to ensure the full loading of efficient plant.

A plan was submitted, in the form of a Report to the Ministry of Supply, in accordance with the Government's request, and this Report has just been issued as a White Paper. That the iron and steel industry welcomes the publication by the Government of this Report, and the recognition by the Minister of Supply that it constitutes a far-reaching plan for the future development of the industry, is understandable. It will be appreciated, however, that the consuming industries, which embrace practically all other industries, are not less interested in a plan to modernise an industry upon whose products they rely for their basic materials.

It must not be assumed that the need for a progressive plan was not fully appreciated by the industry. Indeed, but for the war, it would have been in an exceedingly strong position to-day. It will be remembered that, after various meetings and prolonged discussions over a period of about 18 months, a National Committee of the Iron and Steel Industry was set up in June, 1932. The object was to meet the request that in return for a protective duty the industry must put its house in order and supply the right material at the right price. At that time there was considerable divergence of opinion with regard to the merits and demerits of Governmental intervention or control. Doubtless, a large majority in the industry were of the opinion that Governmental control was not necessary or beneficial to the industry. On the other hand it was generally acknowledged that co-operation with the Government was essential. These views seem to be held as strongly to-day. However, with the formation of the National Committee the plan to reorganise the iron and steel industry commenced and schemes were gradually put into operation which transformed the industry, and although these were not completed in 1939, when war was declared on Germany, it had been raised to a high stage of efficiency; otherwise the magnificent contribution of this industry to the war effort would not have been possible.

During the war the further schemes contemplated had to be shelved and others in progress were brought to partial completion as quickly as possible to permit the whole energies of the industry to be applied to the maximum production of steel. Thus, new installations in this period were few and even the maintenance of existing plant was only such as to keep it in operation. Obviously, after six years hard working, not only are modifications in plant necessary but renewals are urgently needed. This is the position in the industry at a time when the demand for iron and steel for both home and abroad is as great as when the war was in progress. It is to restore the industry that this plan has been put forward. It is a national plan within which schemes in the various districts, and for each of the products, are integrated into one programme of progressive and inter-related development. A summary of the industry's plan as given in the White Paper will indicate that the importance of the task is fully recognised.

A Plan for Iron and Steel

The objects of the plan are:—

1. To make good the further modernisation and development which would have taken place during the last six years had there been no war.

2. To enlarge steel-making facilities to bring them into close relationship with the higher demand for steel products that may be anticipated.

3. To ensure the most effective use of plants by concentrating production into efficient units of appropriate size, with due regard to availability of raw materials and the distance to markets.

At the rate of progress achieved in five years before the war the whole industry would have been renewed by 1950. In facing its task anew the industry proposes a more radical attack on the problem of rebuilding, and it has been able to take advantage of the further technical developments which have taken place during the war. At the same time, it is necessary to bear in mind the difficulties such a task necessarily imposes in a very varied and complex industry when it must be undertaken in the post-war period of readjustment, and in a period of what will be abnormally high construction cost.

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It is pointed out that there has been a marked long-term upward movement in the domestic use of steel in the U.K. The peak figure reached was the consumption of 11,600,000 tons in 1937. It is estimated that home consumption by the years 1950/55 will have reached approximately 13,000,000 ingot tons per annum if a high level of employment is secured. It would seem reasonable to assess the export demand at 3,000,000 ingot tons per annum if this country is to secure the maximum export.

The Report argues that an efficient capacity of about 16,000,000 ingot tons should be aimed at, with average production from this capacity of about 15,000,000 ingot tons, and that provision should be made for the import of 500,000 tons of steel when demand conditions are reasonably normal.

Production would be based on a maximum use of home scrap, which would amount to 55% of ingot output, and involve the import of not more than 250,000 tons of scrap. Hematite and basic pig iron requirements would then amount to 8,500,000 tons, for which 7,500,000 tons of imported ore and 12,500,000 tons of home ore would be needed, excluding the tonnage required for foundry pig iron production. To give the necessary pig iron output, blast furnace capacity should be increased from the present capacity of approximately 7,250,000 tons to 9,000,000 tons.

The industry uses just over 20,000,000 tons of coal a year, of which half is in the form of coking coal. Any interruption of supply has most serious effects on the whole working of the industry, as the operations of an integrated plant depend on the regular supply of gas from coke ovens and blast furnaces. The need to conserve our resources of coking coal has now become imperative.

The primary factors affecting the location of the iron and steel plants are the relative costs of home and imported ore; the required quality of finished products; the cost and quality of coal and coke delivered to various producing centres; the full economic utilisation of gas; distance from markets; availability of personnel, houses and social amenities. Cost considerations make it desirable to increase the proportion of the commoner steels, particularly billets, which are made on a home ore basis. Technical factors, however (for example, the more exacting demands on the steel used in the continuous strip mill) make it necessary to envisage certain types of steel production being developed to an increasing extent on the richer imported ore.

The following table shows the total expenditure involved in modernisation and development:—

	£
South Wales	41,000,000
North-East Coast	35,000,000
Scotland	29,000,000
North-West Coast	1,300,000
Sheffield	5,500,000
Lancashire, Flintshire, Staffordshire, etc.	17,000,000
Lincolnshire	19,200,000
Northamptonshire	20,000,000
	£168,000,000

The plan involves the building of 4,750,000 tons of blast furnace capacity and about 6,000,000 tons of steel ingot capacity. It provides for the stepping up of the rate at which new building is initiated to fully 40% of the industry's capacity in a five-year period. This exceptionally high rate is largely due to the hold-up of new construction during the war. In conjunction with the new building, 3,000,000 tons of present blast furnace capacity and 4,000,000 tons of steel ingot capacity would be scrapped.

The main increase in ingot capacity would be in plants based directly on home ores, the total increase in the Lincolnshire, and still more the Northamptonshire, areas amounting to almost 60%. In the main coastal areas the total increase on balance would be about 7½%. Little net change in capacity is contemplated in those Midland areas which are not directly sited on home ores.

BLAST FURNACE CAPACITY.
BASIC AND HEMATITE.

	Present Capacity Tons	New Building Tons	Future Capacity Tons	Increase Tons
South Wales	1,200,000	600,000	1,600,000	400,000
North-East Coast	2,200,000	1,550,000	2,350,000	150,000
Scotland	650,000	600,000	900,000	250,000
North-West Coast	650,000	—	650,000	—
Sheffield	150,000	—	150,000	—
Lancs., Flint, etc.	250,000	550,000	600,000	350,000
Staffs., etc.	400,000	—	250,000	150,000 (reduction)
Lincolnshire	1,200,000	600,000	1,400,000	200,000
Northants.	620,000	850,000	1,200,000	580,000
	7,320,000	4,750,000	9,100,000	1,780,000

Notable items in the heavy programme of mill construction are:—

1. Five new continuous mills with an average capacity of 450,000 tons each.
2. The erection of a broad flange beam mill on the North-East Coast of 350,000 tons capacity.
3. A new continuous strip mill in South Wales for sheets and tinplates, with a hot strip capacity of 1,000,000 tons a year.

Particular importance attaches to these major projects in view of their potential contribution to the expansion of export trade.

Full loading of efficient plants will be ensured—for instance, on the North-East Coast there are at present nine different steelworks:—

4 produce Rails,
3 „ Plates,
5 „ Billets,
5 „ Heavy Sections.

Under the new plan there will be only five steelworks, of which two would concentrate solely on plates, one on heavy structural materials, one on billets and light and medium sections rolled from billets, and one on rails and special billets. Similarly, over the country as a whole, the number of plants producing heavy rails will be reduced from eleven to four.

The plan involves the construction of blast furnaces with an average annual output of about 200,000 tons a year each. This would bring the average output from all basic pig iron furnaces, which had already risen from 35,000 tons in 1920 to 90,000 tons in 1939, to an estimated average level of 160,000 tons.

CAPACITY BY SECTIONS OF THE INDUSTRY.

	Present Capacity	New Building	Future Capacity	New Building as % of Future Capacity.
	Tons	Tons	Tons	
Blast Furnaces (Basic and Hematite)	7,320,000	4,750,000	9,100,000	52
Steel Furnaces	14,100,000	5,835,000	15,950,000	37
Billet Mills	3,700,000	2,200,000	4,500,000	49
Plate Mills	1,750,000	500,000	1,750,000	29
Joists, Rail and Heavy Sec. Mills	2,500,000	650,000	2,500,000	26
Sheet and Tinplate Mills	2,400,000	1,100,000	2,700,000	41
Wire Rod Mills	675,000	150,000	750,000	20
Light Section Bar and Strip Mills	2,500,000	850,000	2,800,000	30

The supply of rolling mill equipment would be likely to be one of the main factors limiting the rate at which the plan as a whole could be achieved, and it is proposed

that part of this equipment should be obtained from the United States at a cost of about £9,000,000.

The plan as a whole has been carefully balanced to provide units of efficient size, the most effective degree of concentration, the full loading of efficient plant and the maximum reduction on fuel consumption.

Public Ownership

The Government desires to push forward the plan which the industry submitted as a basis of action for the Government and the industry. If this, combined with an appropriate measure of public supervision over the industry, had been the Government proposal, states Mr. Ellis Hunter, President of the British Iron and Steel Federation, the stage would have been set for constructive development over the wide field of industry covered by iron and steel trades, and it would have harnessed the whole energies of the industry along lines which would have had public recognition and encouragement.

It will be remembered, however, about the middle of last month, Minister of Supply, Mr. Wilmot, announced in the House of Commons that the Government had decided on a large measure of public ownership of the iron and steel industry, for which legislation would be prepared. This announcement went much farther than was indicated in the initial invitation to the industry. It envisages a change of ownership over some unspecified part of the industry at some indeterminate stage in the course of executing the plan. The industry's proposals are designed to secure a further large measure of integration with consequent saving in fuel and other costs and greater operating efficiency. To raise questions of demarcation and delimitation of ownership, continued Mr. Hunter, would impede the development of integration. Moreover, problems of scrapping of plant and adjusting production between firms become more complicated when seen in relation to some undefined change of ownership.

Although it seems that the present Government intends to proceed further in the control of this industry than was contemplated, the first steps towards possible nationalisation were undoubtedly taken in June, 1932, when a National Committee of the Iron and Steel Industry was instituted. The influence on the industry of that Committee is very considerable to-day. It was formed to prepare a scheme for the reorganisation of the industry to effect its orderly progress. In a report of its deliberations it was proposed to replace the many existing trade associations within the industry, including the National Federation of Iron and Steel Manufacturers, by a much smaller number of associations concerned with the production of various classes of manufactures. It was suggested that these associations should be co-ordinated by a proposed Iron and Steel Corporation of Great Britain, which would control production and carry into effect national planning for the industry as a whole. It is noteworthy also that in the proposal it was suggested that the Corporation should contain a considerable proportion of the consuming interests.

Not all the recommendations of that Committee were given effect, but it can claim some credit for the good condition of the industry on the outbreak of war in 1939. However, the present position is very critical and unsatisfactory because this question of public ownership makes it essential that there should be discussions between the Government and the industry before the industry can determine how far it is now practicable to proceed with the proposed plan. That there is still considerable divergence of opinion with regard to Government control or public ownership of the industry there can be no doubt, and the sooner the position is clarified the better it will be for the industry and the country as a whole. Meanwhile, we have no doubt the industry will endeavour to maintain and, if possible, to improve upon recent high levels of production and to continue the substantial contribution it has been making to the export trade of the country.

Those familiar with the iron and steel industry will appreciate the progressive nature of the plan; it provides a sound and well-balanced scheme for the modernisation of the industry and, in the absence of any alternative plan from the Government, it will doubtless be the basis upon which progress will be made in the next ten years.

Iron and Steel

From a Luncheon Speech by the Rt. Hon. John Wilmot, M.P.

IN connection with the recent annual meeting of the Iron and Steel Institute, referred to elsewhere in this issue, a luncheon was held at the Connaught Rooms, Great Queen Street, London, in which over 500 members and guests participated. Among the guests was the Right Hon. John Wilmot, M.P., Minister of Supply, who proposed the toast of "The Iron and Steel Institute and Industries." In doing so, he said: As a Minister who is merely a politician and a business man, you may surmise how honoured I am at the opportunity of addressing this learned technical and scientific assembly, for I understand that this Institute is the forum for all interested in the technical and scientific sides of this very great industry.

Rightly or wrongly, this is not the occasion for a political speech, but I believe you will agree with me that in a free country it is proper that there should be more than one point of view. However many points of view there may be on a number of matters, at any rate I think we shall agree upon the tremendous importance of your industry in our national economy. This Institute has a tremendous reputation, and I should like to take this opportunity on behalf of His Majesty's Government of paying a tribute to the work it did towards the successful conclusion of the war.

I think that this Institute and its members have, however, a no less important part to play in the future. Whatever may be the changes that lie ahead, one thing is certain, and I ask you to believe it: their object is to secure the highest possible scientific and technical achievement. To that end this body has a great contribution to make, and it will make it.

The iron and steel industry has had a hard time. It has been hampered by long depressions between the wars, by restriction of its normal development and by the sudden abnormalities of development forced upon it by the necessities of war. By common consent, what is now needed is a large-scale programme of modernisation and development to meet exacting needs and modern conditions. I am certain that the effort which will be required, an effort which must be successful, for the nation depends upon it, will give very full scope to your members.

The Vapour Phases of Metals

By R. C. Vickery, M.Sc., Ph.D.

The thermodynamical basis of metals distillation is surveyed, together with other aspects of the applications of metals vaporisation. The industrial possibilities are collated and data are given of the most important physical properties of the more common metals.

Introduction

THE growing interest in metals extraction and purification by distillation, together with the widening analytical applications of high vacuum technique as applied to metals, is leading to a progressive frame of mind in regard to the vapour phases of metals. Even so however, the application of known thermodynamical data, obtained from a study of the more common distillation processes, is not always so concise as one might anticipate; scattered throughout the literature one finds notes and articles of diverging interests forming the basis of this comparatively recent metallurgical development.

The use of sublimation as a procedure for the refining of such metals as zinc, arsenic, antimony, etc., was well known even to the ancients; but unless the atmosphere was also controlled the result was not so much metal sublimation as oxide formation. The various processes of zinc distillation as nowadays practised are common knowledge to metallurgists, whilst even the lesser used arsenic and antimony present no large difficulties—although in these cases sublimation is the better term. Magnesium is one of the latest additions to the "distillable" metals—the adjective here is used advisably as all metals may be considered to be distillable if the vacuum obtained in the apparatus is low enough; plant design, however, becomes an important factor in commercial applicability of such processes. Owing to the limitations of high temperature and low pressure production and maintenance over a large volume, distillation of metals is at present confined on an industrial scale to metals of comparatively high vapour pressure or those whose boiling points can be reached up to ca. 600° C. under a vacuum of ca. 10^{-2} mm. Hg. It should be noted that the author has expressly given application of these conditions only to industrial processes; under laboratory conditions vacua of 10^{-6} mm. and temperatures of the order of 1,500°–2,000° C. may be successfully maintained. But laboratory conditions and industrial plant differ widely, and further a large amount of work is necessary before the refining of metals, or recovery from scrap, by distillation can be regarded as a basic process. Workers on vacuum fusion of metals, whether from the point of view of analysis, degassing or general investigations can offer valuable information, whilst the study of vapourised metals is of almost essential interest to welding research investigators for elucidation of metal losses. The study of metallic vapour phases can thus be regarded as of interest to all metallurgists, regardless of their speciality.

General Considerations

From a thermodynamical standpoint, it is possible to treat metals distillation in a similar way to normal distillation processes. The relation between the composition of a liquid mixture and that of its vapour has been the subject of many experimental investigations. Theoretical considerations are usually difficult to handle in practise, but for industrial purposes empirically attained relationships are frequently valuable.

To mixtures of liquids for which Berthelot's equation is tenable—*i.e.*, $a_{AB} = \sqrt{a_A \cdot a_B}$ where a_{AB} represents the attraction of the unlike molecules and a_A and a_B the respective attractions of the like molecules, it may be assumed that Brown's formula is applicable:—

$$\frac{m'A}{m'B} = C\frac{m_A}{m_B}$$

where $m'A$ and $m'B$ are the relative weights of the two substances in the vapour and m_A and m_B are the relative weights in the liquid. C is a constant.

With regard to metallurgical considerations, the application of distillation is generally of either initial separation or final purification from another metal—*i.e.*, the study resolves itself mainly to a two component mixture investigation, although many minor elements exert an appreciable vapour pressure which must be taken into account. In a considerable number of cases, the boiling point composition curve for a two component mixture is proportional to the partial vapour pressure of the components and to the product of the vapour pressure of the pure components and their concentrations in the mixture. In most cases the vapour will be richer in the material of greater vapour pressure and separation thus is possible.

It must be remembered that a liquid boils when its vapour pressure is equal to the pressure of the surrounding atmosphere and that the vapour pressure increases with temperature, so that by a decreased pressure and elevated temperature, metals may be vaporised with an ease depending on the vapour pressure of the specific metal.

The change of vapour pressure with temperature is given by the Clausius-Clapeyron equation:—

$$\frac{dP}{dT} = \frac{L}{(V - V')\,T}$$

where dP/dT is the rate of change; L is the latent heat of vaporisation of a gram-molecule; V is the volume of a gram-molecule of the vapour; V′ that of the other phase; and T is the absolute temperature.

Neglecting V′ which is small in comparison with V and replacing this latter by RT/p, by integration we obtain:—

$$\log_{10} p = K - \frac{1}{T}\left(\frac{L}{1{\cdot}985 + 2{\cdot}303}\right)$$

and over a small range of temperature:—

$$\log_{10} p_1 - \log_{10} p_2 = \frac{L}{4{\cdot}571}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

confirming August's:—

$$\log p = \frac{-A}{T} + B$$

for larger temperature intervals we obtain:—

$$\log p = \frac{-A}{T} + B + C \log T$$

but this is only applicable where the difference between the specific heats at constant pressure of vapour and condensed phase may be assumed constant. In cases of non-applicability a multiconstant formula is developed :

$$\log_{10} p = \frac{-A}{T} + B + C \log T + DT$$

Some values for these constants are given in Table I[1], whilst Table II gives the boiling points of some metals at pressures of 1 mm. and 760 mm. Hg. The temperatures at which various metals attain vapour pressures between 10^{-4} mm. and 10^{-7} mm. are given by Ditchburn & Gilmour[2].

Alloys of evaporating metals have a lower vapour pressure than the metals themselves, but the values deviate from the straight line law of Raoult in either direction. Alloys formed by considerable evolution of heat have a lower vapour pressure than that attainable if Raoult's law was valid—the converse is also true.

TABLE I.—CONSTANTS FOR AUGUST'S MULTI-COMPONENT EQUATION

Metal	−A	B	C	D	Phase	T intervals (abs.)
Cu	18,350	14·01	−1·275		solid	800–1,356
	17,700	13·51			liquid	1,356–2,900
Mg	7,636	3·27	2·500	−0·003	solid	573–924
	7,610	11·61	−1·02		liquid	924–1,400
Zn	6,883	9·418	−0·05	−0·0003	solid	473–692
	6,670	12·00	−1·126		liquid	692–1,000
Cd	5,908	9·717	−0·232	−0·0003	solid	450–594
	5,819	12·287	−1·257		liquid	594–1,050
Al	16,450	12·36	−1·023		liquid	1,200–2,800
Sn	17,380	9·28			liquid	1,300–2,800
Pb	10,280	11·43	−1·05		liquid	600–2,100
As	6,160	9·82			solid	600–900
Sb	614	−26·32	8·99		liquid	1,050–1,900
Bi	10,055	12·70	−1·325		liquid	1,000–1,900
Mn	13,260	8·63			liquid	1,500–2,300
Fe	19,500	9·00			liquid	1,400–3,200
Ni	18,000	8·26			liquid	1,400–3,200

TABLE II

Metal	B.Pt. (°K) 1 mm.	760 mm.	Heat of vap'n L_e (calories)	$\frac{L_e}{T_b}$
Cu	1,890	2,830	73,600	26·0
Mg	870	1,375	32,000	23·0
Zn	764	1,180	27,800	23·55
Cd	666	1,041	24,000	23·1
Al	1,880	2,770	69,600	25·15
Sn	1,870	2,700	79,000	29·3
Pb	1,255	2,025	42,700	29·1
As	628	889	28,200	—
Sb	ca. 1,000	1,908	36,800	19·3
Bi	1,165	1,833	41,100	22·4
Mn	1,540	2,300	60,000	26·3
Fe	2,140	3,156	88,200	28·0
Ni	2,180	3,356	82,300	24·5

As Kroll points out ([3, 4, 5, 6]) in the melting and vaporisation of metals in vacuo, the effects of hydrostatic pressure, metal vapour pressure and residual gas pressure are very important. Accurate specification of pressure and temperature for any procedure are highly necessary. Other factors which must be taken into account are dissociation—although this is not a very important one—gaseous contents of the original metals, reaction between the crucible and the melt, etc. Kroll classifies the possibilities of separation of metals thus :—

		Base metal	Impurity
1.	Separation almost complete; impurity is in the distillate	Be	Ca, Ba, Mg,
		Fe	S, P, Cu, Mn,
		Cu	Ag, Bi, Pb, Zn, Cd,
		Al	Mn, Zn, Mg, Na
2.	Separation almost complete; impurity is in the residue	Fe	N
		Be	C, Fe, Ni,
		Cu	Au
		Al	Fe, Ti, Cu
3.	Separation incomplete; impurity mainly in the distillate	Ni	Cu
		Fe	Cr
		Cr	Al, S
		Cu	S, Sb
		Ni	Cr
4.	Separation incomplete; impurity mainly in the residue	Fe	Ni, Co, C, Si
		Be	Si
		Al	Si
		Cr	Fe
		Cu	Ni, O
		Ni	Fe
5.	No separation; nearly equal distribution	Be	Al, Mn
		Cr	Si
		Cu	Fe, As, Sn
		Ni	Co

Kroll has introduced an interesting point however, as he shows that metals are, theoretically, not fusible in high vacuum for, by slow heat addition sublimation occurs. In practice, however, by rapid energy addition melting does occur.

Fundamentally, however, it is obvious that the process of distillation depends upon the difference in vapour pressures of the component of a system, and intrinsically upon the vapour pressures of the individual elements. Several methods have been introduced for the determination of these values and Eucken[7] compiled a critical survey of these various methods. For methods of comparatively high vapour pressures, it is probable that the method of effusion as employed by Egerton *et al*[8] is perhaps the most applicable. For lower values, no really first class method has as yet been devised, although Fischer's modifications[9] of the boiling point and spring balance methods show a considerable advance in applicability. One point which might lead to some clarification of the vapour pressures of metals as determined by the effusion method, is the discovery of Baukloh and Altland[10] that the rate of vaporisation of manganese and molybdenum is increased greatly by the application of an electric field whilst heating under vacuo. At 800° C. the rate of vaporisation of manganese was increased by 100%. By correlation of the field intensity with vacuum and temperature the vapour pressure can easily be determined by use of the Langmuir equation as extended by Van Liempt[11] who considered also the number of atoms on the surface of a metal which have a mean energy equal to the heat of sublimation, thus deriving an equation for the rate of sublimation of regular metals in vacuo :—log M (gm./sq. cm./sec.) =

$$(E/4{\cdot}57T) + \log \sqrt{AT_s}/V + 5{\cdot}15$$

where E = heat of sublimation in Gm.cals./Gm. atom
A = Atomic weight.
T_s = Absolute temperature.
V = Atomic volume.

the sublimation pressure curve is given by :—

$$\log p \text{ (atm)} = -(E/4{\cdot}57T)\ 3{\cdot}47 + \log \sqrt{T.T_s}/V$$

whilst heat of sublimation at T_s is given by :—

$$E = 4{\cdot}57T_s\ (3{\cdot}47 + \log \sqrt{T_s T_s}/V)$$

van Liempt found also that the final function

1 Jellinck & Waunov, *Z. Elektrochem*, **41**, 392, 1935.
2 *Rev. Modern Physics*, **13**, 320, 1941.
3 *Tr. Electrochem. Soc.*, **87**, 1945 preprint 6.
4 *Metal Industry*, **47**, 3, 103, 156, 1935.
5 *Z. Elektrochem.*, **42**, 873, 1936.
6 *Metall. u. Erz.*, **29**, 365, 1932.
7 *Metallwirtsch*, **15**, 27, 63, 1938.
8 *Proc. Roy. Soc.*, **A108**, 469, 1923.
9 *Tr. Roy. Soc.*, **234A**, 177, 1935 and *Z. Anorg. Allgem. Chem.*, **219**, 1934.
10 *Metallwirtsch*, **15**, 650, 1939.
11 *Rec. trav. chim.*, **54**, 847, 1935.

$\log \sqrt{T_1 T_2/V}$ was nearly constant for 14 metals. The relationship of heat of sublimation to vapour pressure being well known the value of the vapour pressure may thus be determined with enhanced accuracy since by utilising an electric field a greater amount of material may be vaporised under given conditions thus leading to a greater accuracy in weighing.

The relation between surface tension and vapour pressure also is of interest as the former phenomenon must be taken into account when the problem of superheating of the melt is encountered, leading to contamination of the distillate by elements of higher boiling point. An equation was proposed by Pollara[12] for the relation :

$$T \log p = -a (M/(D-d)^{2/3} \gamma + T_c \log P_c$$

where a is a constant, M is the molecular weight and D and *d* the densities of the liquid and vapour respectively. The applicability of this formula has not been generally ascertained as yet however.

The influence of attendant metals on the vaporisation of any specific metal is of exceptional importance, as not only are surface tension and partial vapour pressures affected but, as Bosnjakovic[13] points out, the equilibrium—liquid/vapour—depends upon the composition of the two as well as on the temperature and pressure, whilst distillation does not occur at equilibrium and varies with composition and temperature or both. As an example Yamauchi and Hamada[14] investigated the influence of metals on the vaporisation of zinc from brass and found that 2% of lead, tin or iron greatly increased the loss, whilst aluminium decreased the loss.

Applications

The industrial utilisation of differences in vapour pressures, or of high vapour pressures, of metals, apart from ancient practices was probably ushered in in the late 19th century. The zinc distillation process was well known early in that era, but the patent situation began to clarify only in about 1898 when a German patent (104990) was filed for the separation of zinc from silver by heating in vacuo. From then until the beginning of World War I, many applications were filed of which probably the most prominent were those relating to arsenic and antimony, although several general patents were taken out on grounds of applicability[15]. In 1913 Nair and Turner[16] investigated the volatilisation of zinc and cadmium in vacuo with a direct bearing on the industry, and indicated that alloys of those metals with 40% copper could be separately volatilised and recovered as metals, but with less than 40% copper the distillate was impure. Although their work was carried out under temperatures up to 900° C., no indication was given of the degree of vacuum employed, so that their work was not of direct application. After the 1918 armistice, attention was directed, mainly as the result of research during the war years, to the lighter metals and consequently much work was carried out on the distillation of aluminium and magnesium, when for the former metal temperatures up to 1,400° C. were employed. A far lower temperature was used by Burgess[17] who heated aluminium carbide with a chloride to obtain a volatile aluminium chloride which distilled over at 300° C.

The investigations carried out by the Dow Co. on the extraction of magnesium from sea-water were accompanied by a further series of researches by other concerns on purification of that metal by distillation. Kaufmann and Liedler[18] showed that the range for distillation is at least from 650° C. with a pressure of 2 mm. Hg. and that sublimation only can be effected between 500°–600° C. at pressures of 0·5–2 mm. Hg. To a certain extent this was confirmed by Hérenguel[19] who, with Chaudron, described an apparatus for the purification of 1 kilo. of magnesium per hour at 600° C. and 0·01 mm. Hg. This performance has been far transcended since that date. Plant for the production of magnesium from dolomite by the ferrosilicon reduction process under vacuo with concurrent sublimation was given by Mayer[20] who quoted temperature and pressure conditions of 1,165° C. for 9½ hours with pressure reduced to 65μHg. after 5 hours and 45μ after 9 hours.

Recent industrial developments have, however, shown a marked divergence from large scale distillations for metal production, and are producing a flood of results from workers on light filaments and metal coatings. Even in 1932, Hawley-Cartwright had described apparatus and technique for the formation of mirrors of silver, beryllium and chromium by distillations[21], his method and results being followed up by James[22]. The formation of gold alloys by such methods was the subject of a paper by Sommer in 1943[23] who thus obtained a series of layers —pure metal—alloy—alloying elements. The possibilities of such a sequence in anti-corrosion measures needs no comment. The results obtained by Gulbransen[24] may not be misplaced at this juncture. This worker employing a vacuum micro-balance, studied the evaporation of magnesium between 400° and 500° C. He found that the heating curve was composed of an initial evaporation period, an oxidation period and a final evaporation period. The oxidation curves at 475° and higher are linear with time, at 450° and lower the weight curves follow a linear law, but as the oxidation film builds up, the rate of oxidation diminishes. Analysis of the relationship between oxidation and evaporation curves indicates that oxide films of 700A or more, at 475° are extremely porous to the evaporation of the metal. At 450° and lower all the films measured were protective to the evaporation process. Films found to be protective to evaporation were similarly protective to oxidation. Once again the application of these findings—initially of academic interest only to workers on metallic vapours —is highly instructive from the anti-corrosion aspect: films produced on magnesium at 440°–450° C. would apparently present a very high degree of resistance to oxidation-corrosion.

In discussing the early days of nickel—tungsten powder metallurgy, Pirani[24] stated that in 1907–09, filaments of nickel and tungsten were mounted in lamp supports and heated to temperatures of over 1,500° C. in vacuo in order to boil out the nickel and leave the tungsten filament *in situ*. This surely must have been one of the earliest applications of distillation of the metals of lower vapour pressure. It is interesting to observe that after some thirty years the same process

12 *J. Phys. Chem.*, **46**, 1163, 1942.
13 *Forsch. Gebiete. Ingenieurs.*, **A or B 3**, 213, 1932.
14 *J.C.S., Japan*, **52**, 668, 1931.
15 Brit. Pat. 2782, 1901, U.S. Pat. 996,474; 1911. Brit. Pat. 19781, 1905, U.S. Pat. 998,665, 1911. U.S. Pat. 959,785, 1910.
16 *Tr. Chem. Soc.*, **cii**, 1534, 1913.
17 U.S. Pat. 1,321,281.
18 *Z. Elektrochem.*, **37**, 492, 1931.
19 *Compt. rend.*, **193**, 771, 1931.
20 *A.I.M.M.E. Tech. Publ.*, 1670, 1944.
21 *Rev. Sci. Instr.*, **3**, 296, 1932.
22 *J. Sci. Instr.*, **11**, 167, 1934.
23 *Nature*, **152**, 215, 1943.
24 *Electrochem. Soc.*, Preprint **85-22**, 231, 1944.
25 Olsen *et al. J. Appl. Phys.*, **16**, 425, 1945.

should have been investigated by Olsen and his co-workers[25] who included that system in their work on the behaviour of some thirty-four elements when evaporated from filaments of tungsten, nickel, iron, chromel, etc. temperatures of 2,000° C. being reached.

The literature on metals distillation is, as has been observed above, concerned mainly with zinc and cadmium, with a sprinkling of reports of work on arsenic and antimony, etc., the majority of patents refer to design of plant, etc.; with modifications for individual preferences and it is impossible in this short survey to refer to all available literature. It would not be politic, however, to abstain from referring to yet another field to which metals vaporisation is becoming applicable—analysis. The original paper relating to the analytical applications of distillation principles as applied to metals would be difficult to determine, but in 1930 an indication of the accuracy which could be attained by such a method was given by Tamman and Dreyer[27] who demonstrated that not only were separate rings, corresponding to the original constituents, formed in a glass condensing tube, but that impurities of the order of 0·01% showed separate identifiable rings when pressures of 0·001 mm. Hg. were employed. The application of the principles outlined above, to ferrous materials, has been almost the monopoly of Sloman[28] although in the case of this worker attention has been mainly given to gaseous non-metallic inclusions—recently, however, a further communication[29] indicated that his attention has been diverted to the non-ferrous materials, and it is to be anticipated that more valuable information will be forthcoming. With specific application to the analysis of brass, Treadwell and Frey[30] applied pressures of 10^{-4} mm. Hg. and temperatures of 800°–850° C. and obtained some interesting results. Diffusion of the volatile elements from the centre of the mass to the surface is apparently the rate determining factor during the major part of the operation, although towards the end of the zinc removal, adsorption of the vapours of this latter metal on the copper is apparently rate determining. Lead is volatilised with the zinc but forms a separate zone on condensation. Price also estimated zinc and lead in copper—tinbase alloys under a pressure of 0·05 mm. Hg.—his results are, in general, confirmation of those already reviewed, but several points arouse interest, namely: antimony is not removed from tin at 800° C. and only slowly at 850°; 5% phosphor-tin is completely and rapidly dephosphorised at 250°–300° C. The addition of tin in cases of comparatively high melting point alloys is also practised by this worker, although it appears that this has no effect on the removal of lead from Cu-Pb alloys. With phosphor-copper, no loss in weight was observed during the experiments; this however is not clarified, but on the basis that Cu_3P_2 decomposes on heating, it must be assumed that the material employed by Price must have consisted mainly of copper and the triphosphide.

26 *Tr. Electrochem. Soc.*, **87**, 1945.
27 *Z. Anorg. Allgem. Chem.*, **190**, 53, 1930.
28 *J. Iron and Steel Inst.*, Spec. Rept., 16, 1937.
ibid. 25, 1939.
J. Iron and Steel Inst., **143**, 298, 1941.
ibid. **148**, 236, 1943.
29 *J. Inst. Met.*, **71**, 391, 612, 1945.
30 *Helv. Chim. Acta.*, **27**, 42, 1944.
31 *J.S.C.I.*, **283**, 64, 1945.

Conclusion

However brief the foregoing survey may be, it is hoped that it may provide an addition to the literary foundation on which further research on metal vapours may be based. The scope in this field is vast, as may be evidenced by the few indications given above. From the academic standpoint, the application of electric fields in the determination of vapour pressures, should, as the author points out *supra*, produce some interesting results. That metallurgists are becoming more attentive to the possibilities of metals distillation is obvious from the increasing amount of literature on the subject, but even so, much has yet to be done from all view-points in order to elucidate the basic phenomena and to place this comparatively new metallurgical development on a firm foundation.

Sulphamic Acid in Electrochemical Processes including Anodic Oxidation

From a Correspondent

During recent years sulphamic acid has been successfully applied to a number of electrochemical processes and has entered the field as a suitable electrolyte in the anodic oxidation process. This brief résumé of some of the work carried out with this acid indicates hopeful possibilities of its application for the electrodeposition of several metals.

TAKING anodic oxidation of aluminium first, another acid (sulphamic) entered the field as rival to chromic, sulphuric, and oxalic acids, two or three years ago, as a suitable electrolyte in this important process; and was successfully tried out still earlier in some other electrochemical operations, such as lead refining and electrodeposition of other metals, such as copper, zinc, cadmium, etc.

Among much recent interesting work on anodic oxidation, including that of Samartsev in Russia, Keller and Edwards in the U.S.A., and Lacombe and Beaujard in France, that of Piontelli in Italy on sulphamic acid merits special attention. Since this acid was first produced on a commercial scale in the U.S.A., as described by Cupery[1], some of its industrial applications suggested at that time have been investigated; but these did not include the electrochemical field, certain aspects of which were subsequently studied both in U.S.A. and in Canada, to which brief reference is made hereinafter. In Europe, the principal work appears to have been done in Italy, by R. Piontelli, of Milan University, who, in 1938–9 secured several Italian patents, Nos. 368824, 381860 and 388932, among others; and recorded some of his work.[2]

Like other workers on anodic oxidation, e.g., Samartsev in Russia ("Oxide Coatings on Metals,"

1 *Ind. Eng. Chem.*, 1938, **30**.
2 *Metallurgia Ital.*, also in *La Chim. e l'Ind.*, 1939, **21**, 478, and 1940, **22**, 65.

Acad. Sci. U.S.S.R., Moscow, 1944) and Lacombe and others[3] in France, Piontelli also is of opinion that the structure and properties of oxide coatings on aluminium have by no means yet been fully and satisfactorily explained. He does not pretend to offer much by way of explanation, but considers that two factors at least are fairly definite and well established (1) an oxygen-containing anion must be present in the electrolyte, and (2) this latter must have a certain amount of solvent action on the aluminium. If solvent action is too weak oxide formation ceases too soon. The author states that in some of his unpublished work the kinetics of aluminium solution under varied surface conditions in sulphamic acid is shown to be somewhat analogous to that of sulphuric acid, though there are also marked differences. Generally he claims that good results have been obtained, especially in working with saturated solutions.

As with chromic baths, voltages rise rather quickly to high values and need proper control. Optimum conditions include a temperature range of 30–40° C., and a c.d. not exceeding 100 amp./m², or rather lower than with sulphuric acid. For approximately the same duration of treatment the coatings produced in the sulphonic baths are somewhat thinner but less porous and more dense than with the sulphuric baths. It is of great interest and importance to note that, even without after sealing or finishing, efficient protection against corrosion is claimed. The complete treatment as described by Piontelli comprises: Five seconds immersion in caustic soda solution at 50°, another water rinse, five seconds immersion in nitric acid at 50°, another water rinse, when thus thoroughly cleaned beforehand, anodic oxidation at 35° in sulphamic acid solution, with a gradually rising potential for 45 min., up to about 45 volts, followed by a final water rinse. Concentration of acid solution is not stated. Good corrosion-resistant properties are claimed.

Results of work on electrodeposition of other metals, using a sulphamic acid electrolyte may be tabulated as follows :—

Metal	Metal conc. g/lit	Free acid g/lit	c.d. amp./m²	Temp. °C.	Remarks
Rhodium ..	2–12	10–50	up to 1000	normal	prepared from hydroxide, with Pt anodes, good coatings.
Silver ..	..(no marked advantages over sulphuric, see below).				
Copper.. ..	—	30–80	up to 1000	—	very dense finely cryst. coating; glue as additive.
Iron	—	—	about 300	25	good results improved by addition of glycerine.
Nickel	—	10–40	up to 400 or higher	45	good results improved by addition NaCl, boric acid or ammonium sulphamate.
Cobalt (similar to Ni)	—		100	25–30	ditto
Ni-Co alloy.. ditto					
Lead (See below).					

Zinc, cadmium, manganese, thallium; no particular advantage over sulphuric, except possibly in the case of cadmium with glue and nickel sulphate as addition agents.

It is clear from the above that addition agents can play an important part in sulphamic acid baths. In the case of lead, dendritic coatings are obtained from solutions of lead bi-sulphamate with small additions of free acids, fish glue (4–8 g/lit) when the free acid content is up to 50 g/lit, together with some naphthol and aloin, using a c.d. of about 80 amp./m².

Mathers and his students[4] in U.S. have studied the effect of a large number of different addition agents to sulphamic acid baths.[4] For baths containing 54g/lit. lead and 50g/lit sulphamic acid, at room temperature, with a c.d. as low as 21·5 amp./m², casein, cresylic acid, and other additives are beneficial. The authors suggested the use of such baths in lead refining, as they seem to offer certain advantages such as greater stability, higher efficiency, whilst the almost complete insolubility of the usual bismuth, arsenic, antimony and tin impurities is an important factor. Further study of addition agents, despite the large number already tried, should prove of interest. These authors like Cupery (loc. cit.) describe the acid as rather strong, with ionisation of 77·1% in 1/32N solution at 25° C.; stable, non hygroscopic, mono-basic, and moderately water-soluble. It reacts readily with metallic oxides, hydroxides and carbonates, to produce water soluble salts of lead and other heavy metals. In many of Piontelli's baths the solutions were prepared from the metal hydroxide or carbonate. The acid is said to be non-corrosive, and can be easily handled or stored without risk. For further details of properties, etc., see Cupery (loc. cit.)

The suggestion in regard to lead refining is of particular interest. As a matter of fact, in the discussion of Mather's paper[5], A. H. Wilson Busby, Research Engineer of the Consol. Mining and Smelting Co. of Canada, Ltd., described experiments on a somewhat larger scale on the use of sulphamic acid solutions in the Betts electrolytic lead refining process, using anodes of bullion lead, a c.d. of 17 amp./sq. ft. (1·83 amp./dm²) at room temp. Best results were obtained with high acid concentration, up to 100–110g/lit. free acid, and 50–60 g/lit. lead. The author's (Mathers) statement about corrosion appeared, in Busby's view, to require qualification. It had been found rather strongly corrosive of metals and ceramic or wood equipment had to be used.

In regard to silver, this could almost be placed in the same category with zinc, etc., as offering no marked advantages. Piontelli reports that baths prepared by solution of silver carbonate in sulphamic acid gave fairly satisfactory coatings, but with some larger crystals than with the cyanide baths; and no improvement could be obtained by change of acid concentration or temperature or with the usual additives recommended for the nitro baths; though tartaric acid, say 1 g/lit. with 25 g/lit. silver as sulphamate, seemed to improve the result. It also appeared more easy to remove impurities. As with lead, further study is suggested for silver refining, as offering hopeful possibilities, even if, for protective or decorative purposes, no great advantages are apparent over the usual methods. As a suggestion for further work tests might be made with ammoniacal solutions of the complex salt, potassium-silver sulphamate.

3 *Chim. et Ind.*, December, 1945, 389–395.
4 *Trans. Am. Electrochem Soc.*, 1939, **76**, 371.
5 ibid., 1940, **78**, 420.

Aluminium in Store Architecture

APPLICATIONS of aluminium and its alloys in architecture and decoration are nearly as old as the aluminium industry itself, but it is interesting to see, in a recent brochure published by the British Aluminium Company Ltd., the remarkable effect of this use in the Escalator Hall of Messrs. Harrods Ltd., Knightsbridge, London S.W.1. The condition of this escalator installation after six years' service under arduous wartime conditions, not only enhances the reputations of the architect and those firms who co-operated in the design and installation, but also drives home the suitability of aluminium for such purposes.

One of the many purposes for which the Jeep is now being applied.

The Metallurgy of the Jeep*

By Roger F. Mather

Chief Metallurgist, Kaiser-Frazer Corporation

Thorough-hardening Alloy Steel Forgings

Alloying elements are added to automotive steel forgings for several purposes, the chief of which is to increase hardenability in order to secure greater response to the quenching of large sections. Unlike those encountered in some other kinds of products, such forgings are almost invariably used in the hardened and tempered condition. The limiting size beyond which alloys are required to secure thorough hardening on quenching depends on the carbon content of the steel and on the severity of the quench, but is usually about ½ in. diameter with a carbon content of 0·40%. Alloy steels are often preferred for parts tempered to higher hardness values, because the quenched hardness is greater and a higher tempering temperature may be used for a given final hardness. Alloys are also used for improving special properties such as resistance to corrosion and erosion, creep at high temperatures, and wear and abrasion.

Another common reason for employing alloy steels for automotive forgings is the closer control and inspection exercised during their making, which result in a more uniform product and in lower rejections during fabrication at customers' plants. For example, Willys-Overland has consistently used alloy steel for steering arms for many years because no failure in these parts can be tolerated. The higher quality standards of alloy steels give rise to their higher base price as compared with plain carbon steels, in many grades an "extra" greater than that for the alloy content. As an instance of quality control, test pieces are checked for ingot structure and response to heat-treatment. In some mills, heats of alloy steel are followed by metallurgical observers during their melting, teeming, and rolling, in order to check that the proper procedures have been used in their manufacture, and to obtain data for correlating the steel-making practice with the fabricating properties. Many grades of alloy steels are specified with narrower carbon ranges than the corresponding plain carbon grades. Numerous grades may now be purchased according to a guaranteed range of Jominy hardenability, in which case the chemical requirements are slightly relaxed. This optional method of specification may eventually be available on all alloy grades, depending chiefly on the development of a universally accepted method for measuring the hardenability of low carbon steels.

Steels of different chemical compositions possess the same tensile properties—tensile and yield strengths, elongation, and reduction of area—when thoroughly hardened and then tempered to the same hardness, at least below 400 Brinell. The impact and fatigue strengths of such steels are also to a considerable degree independent of their analyses. As a result it is generally agreed that steels of equal hardenability may be safely interchanged as far as tensile properties are concerned, providing they are tempered to the same hardness. The hardenability of a proposed new grade can be predicted with a fair degree of accuracy from its composition. To a large extent therefore the choice of alloying elements for increasing hardenability depends on commercial factors such as cost and availability, although certain limitations and preferences result from metallurgical considerations. For example, steels containing more than 2% manganese are inclined to be brittle, particularly if the carbon is high. Nickel and silicon possess considerably less hardening power than some other alloys, so that silicon is principally used for deoxidation alone, while nickel is most often used in combination

* *Continued from April issue*

with chromium and molybdenum, or both. Chromium, like manganese, imparts brittleness when present in large amounts, and is therefore combined with such elements as nickel, molybdenum, and vanadium in the more highly alloyed constructional steels. Those grades in which the commercial and metallurgical aspects have been unsatisfactory have soon passed out of use.

Alloys also differ greatly in their effect on special properties: nickel and copper are employed for improving corrosion resistance, molybdenum for creep resistance, and nickel and molybdenum for toughness at low temperatures. The alloying elements further affect to varying degrees the fabricating characteristics such as rolling, forming, deep drawing, forging, machining, and heat-treatment. Generally speaking, alloy steels are more difficult to fabricate than plain carbon steels, and the greater cost of these operations must be considered in addition to the increased price of the raw materials. The higher the properties required in the finished part, the greater the difficulty of shaping it into final form. In the extreme case of turbine blades subject to high stresses, high temperatures, and corrosive gases, some of the alloys employed are so unworkable as to require precision casting to size, followed only by a final grinding operation.

The principal forgings in the Jeep made of the so-called thorough-hardening alloy steels include the Pitman arm, steering arms, drag link bell crank, spring clips, intake valves, rear axle shafts, and Tracta front axle shafts and wheel spindles. In all of these parts except the intake valves, alloy steels are used solely for the purpose of increasing the hardenability. They are all quenched in oil, and most are tempered to a mean hardness of 300–360 Brinell. Carbon contents from 0·37–0·42% mean of range and a variety of alloying elements have been successfully used at one time or another. The "p" value* and impact strength are not appreciably affected by carbon content in this neighbourhood, which affords a reasonable margin of safety on quenching. Fine grain size (A.S.T.M. Rating Nos. 5–8) is specified, in order to secure maximum "p" value and to avoid grain growth on heat-treatment. Wherever possible, the steel is purchased according to guaranteed hardenability limits because they are narrower than those obtained by using the chemical specifications alone. Open-hearth rather than electric furnace steel is employed for all alloy steel parts in the jeep except those made from stainless steels, namely the exhaust valve heads and the heat control valve shaft. Physical properties after heat-treatment are specified in the same way as on plain carbon steel forgings.

A variety of optional grades of steel were originally specified for these forgings, principally 1340 (0·40% carbon, 1·75% manganese), 4042 (0·42% carbon, 0·25% molybdenum) and 4140 (0·40% carbon, 1·00% chromium, 0·20% molybdenum). These grades were selected largely on the basis of availability, which is particularly important for purchases in less-than-heat lots. With the advent of war-time shortages of ferro-alloys, the triple-alloy National Emergency steels were introduced, being formulated in such a way as to minimise the additions of virgin materials by making the greatest possible use of the nickel, chromium, and molybdenum residuals, which moreover would otherwise be undesirable. Of these steels, the 8600 and 8700 series contain 0·20 and 0·25% molybdenum respectively, together with about 0·90% manganese and 0·50% nickel and 0·50% chromium; the 9400 series contains about 1·00% manganese and 0·50%, 0·40% chromium, and 0·12% molybdenum. In general, the 8600 and 8700 series have been well received by both producers and consumers. On the other hand, the 9400 series has met with some disfavour among producers because residuals frequently exceeded maximum alloy contents, necessitating diversion of heats, and among consumers chiefly because of the high cost and low hardenability. However, metallurgical and dynamometer tests showed that all three series were capable of meeting every requirement of the Jeep for thorough-hardening alloy steels, partly because of relatively small cross-sections, partly because of the ample factors of safety.

DATA FOR DETERMINATION OF PHYSICAL PROPERTY SPECIFICATIONS FOR CONNECTING ROD.

Tensile Strength, P.S.I.	No. of Tests	Yield Ratio, %	No. of Tests	"P" Factor	No. of Tests	Charpy Impact, Lb./Ft.	No. of Tests
100,000	18	72	14	78	3	28	6
102,000	34	74	28	80	1	30	8
104,000	28	76	47	82	—	32	28
106,000	20	78	37	84	5	34	20
108,000	30	80	28	86	5	36	29
110,000	17	82	12	88	5	38	19
112,000	17	84	13	90	22	40	30
114,000	16	86	4	92	37	42	7
116,000	5	88	5	94	36	44	7
118,000	3	90	—	96	48	46	4
		92	1	98	24	48	1
				100	2	50	3
						52	1
						54	2
Total	189	Total ..	189	Total ..	189	Total ..	165

NOTE: Yield Ratio = Yield Strength/Tensile Strength.
P = Tensile Strength/1,000 + 6 × Reduction of Area/5.

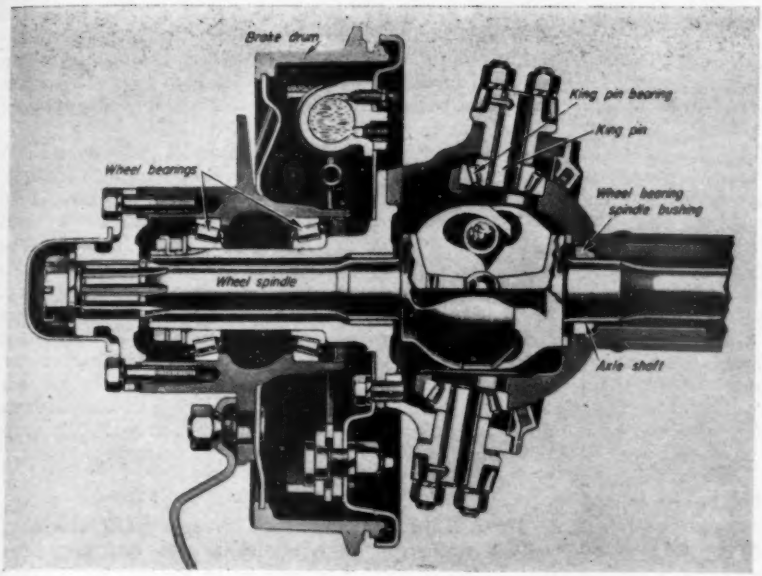
Material Specification for Connecting Rod Material
H.R. Steel, Fine Grain Size, A.I.S.I. C–1141.

Heat-treatment.
Harden in Oil and Temper to 228–255 B.H.N. on Flashline of Boss Quenched Hardness 37 Min. Rockwell C. at Centre of Test Bar.

Physical Properties.
Test Bar: 1 Min. Sq. Forging Heat-treated with Parts.
Tensile Strength .. .. 100,000–120,000 P.S.I.
Yield Strength, Min. .. .. Tensile × 70%.
Reduction of Area, Min. .. .. .. (71–Tensile/6,000) %.
Charpy Impact Min. .. .. 28 ft. lb.

Predictions as to which grades of alloy steels will be the most popular during the post-war era can only be tentative at present, since their relative prices are subject to revision. The 8600 and 8700 series have already joined the ranks of the standard alloy steels, and are no longer considered merely war-time substitutes. However, their present prices are hardly justified by their hardenability and other properties, so that their original steels will be specified unless the price of the newcomers is considerably reduced and the availability remains sufficient. At present the price of the 9400 series is higher than the 8600 and 8700 series, which will be illogical when the residuals have been sufficiently lowered through dilution of scrap by pig iron. The trend toward single-alloy steels will be led by their speed and simplicity of steel-making practice. The trend in the opposite direction will be governed by the amounts of the residuals, taking into account the paradox that a steel containing several different alloys of equal hardening power has greater hardenability than one containing the same total amount of any one of them. The relative merits of nickel, chromium, vanadium, and other ferro-alloys for improving hardenability and other properties can be argued long and deep, but the deciding factor will be the effect on the cost of the finished part. Surveys have

* In parts subject to vibration and deflection under load, rigidity is sometimes of more concern than strength, in which case stresses may be relatively low.



Section of front wheel fitment showing Bendix-Weiss universal joint, brake-drum, axle shaft, wheel spindle and bearings.

shown that a larger ratio of electric furnace to open-hearth alloy steel may generally be anticipated postwar as compared with prewar. However, it is doubtful whether the automotive industry will share this increase in the use of electric furnace steel, at least unless the price is made sufficiently comparable to that of open-hearth steel, a possibility that appears unlikely.

Another important unknown is the future price trend of the Special Addition Agent steels, which are made by adding such materials as Grainal and Ferro-Boron to plain carbon and alloy steel. A principal use of these agents is to improve hardenability, and their popularity for this purpose will likewise depend on their effect on the cost of the finished part. They possess an advantage over other alloying elements in that they do not affect the fabricating properties, so that they may offer considerable economies at the consumer's plant when substituted for conventional alloy steels of equal hardenability. In the case of the Jeep, plain carbon S.A.A. steels would probably suffice, since the leanest of the present alloy steels are satisfactory. S.A.A. steels also show some advantages as regards physical properties when compared with conventional steels, namely greater toughness at high hardnesses and slightly increased "p" values at all hardnesses.

Carburised Alloy Steel Forgings

The principal carburised alloy steel forgings in the Jeep are the transmission and transfer case gears and shafts, differential gears and shafts, hypoid ring gears and pinions, king pins, Tracta male and female joints, and Bendix-Weiss front axle shaft and wheel spindles. Alloy steels are used for these parts because their sections are too large to harden otherwise on quenching, in view of the low carbon content; the core hardness must be adequate to support the case. Moreover, alloy steels are sold as being of guaranteed carburising quality. Fine grained steels are specified to avoid the necessity of double quenching. Most of the parts are gas carburised to a mean depth of about 0·030–0·040 in., and are then quenched in oil—often with fixtures—without reheating. They are finally tempered at about 300°–400° F., yielding a hardness in the neighbourhood of 60 Rockwell C. Apart from chemistry and grain size, property specifications are confined to case depth and hardness. At the same time, gears have been among the most difficult problems in automotive metallurgy, so that extensive dynamometer and other tests are made before any substantial change in materials or design is approved. Pitting, scuffing, and chipping, rather than actual breakage, are the chief causes of failure on these tests.

Prior to the war, 4027 (0·27% carbon, 0·25% molybdenum) and 4620 (0·20% carbon, 1·75% nickel, 0·25% molybdenum) were the grades most commonly used for carburised alloy steel forgings. Carbon contents of the 4000, or Amola, series are generally higher than in other grades because of the low alloy content and because the hardenability is further decreased by the extremely fine grain size resulting from the molybdenum. More recently, 8620, 8720, and 9420 (all 0·20% carbon) have been used for all parts in this category with excellent results, as in the case of the thorough-hardening alloy steel forgings. Again, two or more optional grades are specified for each part, for the sake of flexibility. Costs will be the predominant factor in deciding which steels will be preferred during the post-war period. Special Addition Agent steels would appear to be particularly useful for carburised parts, since they possess high impact resistance at high hardnesses; at present, however, this possibility has not been sufficiently confirmed by actual experience.

Bolts, Screws and Studs

As far as possible, stock items of bolts, screws, and studs made for the trade are utilised in the Jeep, in the interests of cost and availability. In the lowest category of these parts, no chemical or physical properties are specified; 1010 steel (0·10% carbon, 0·40% manganese) is used if the parts are to have rolled threads and upset heads, while 1112 steel (Bessemer screw stock) is used if the design is such that rolling or upsetting is impossible, so that machining is required instead. In the intermediate classes, plain medium carbon steels are used, with maximum and minimum hardness limits stipulated. In some cases these parts are hardened and tempered, while in others they are merely stress-relieved after cold working.

Hardened and tempered alloy steel is required for the highest grade of these parts, for which stock items are less frequently used and for which material specifications are therefore often written by Willys-Overland. Locations in which such parts are used include the connecting-rod

cap, crankshaft-bearing cap, generator-support insulator, cylinder head, steering arm, and wheel hub. Fine grained alloy steel with 0·30–0·40% mean of carbon range is specified, almost any of the regular alloy grades being adequate. The parts are hardened and usually tempered to 321–375 Brinell. Where possible, a standard or subsize specimen is cut from the bolt for complete tensile testing; otherwise the test for tensile strength is performed on the part itself without special machining. In the latter event, experience has shown that the minimum tensile strength in pounds of a new part can be predicted from the formula: (Minimum Brinell × 500–5,000) × (Mean of Pitch and Root Cross-Sectional Areas). The yield strength can seldom be determined, and ductility is specified by means of a bend test or an impact test in which the part, without special machining, is clamped and struck as in the Izod test. Decarburisation is not specified at present, since no difficulty has been experienced from this source. However, data has been accumulated so that decarburisation may be specified at any time it appears advisable.

In some instances the performance of bolts, screws, and studs has little connection with the calculated stresses and physical properties, due to high initial tension imposed during assembly. This tension must therefore be controlled, and a torque wrench gives an approximation that suffices for most automotive work though errors are caused by the varying amounts of friction between the matting threads. Where this error cannot be tolerated, as in some aircraft assemblies, the initial stress must be determined by an extensometer applied to the part under tension.

Sheet Metal Parts

The metallurgy of parts made from sheet metal is simplified in the Jeep by the absence of the deep drawn hoods and fenders commonly found in passenger cars. In both kind of vehicle, however, details of the steel—such as hardness, heat-treatment, microstructure, cupping test performance, and the chemical analysis—are left to the discretion of the supplier, with the stipulation that the steel must be satisfactory to form the part. The hood, fenders, and other exposed body parts of the Universal Jeep, like those of other civilian vehicles, are made of cold-rolled steel in order to improve the finish. Hot-rolled steel was used for these parts in the military version because matt paint was applied and because a cold-rolled finish was not required for deep drawing purposes.

The frame of the Jeep was originally designed for manufacture from 1020 steel (0·20% carbon, 0·40% manganese), but was later redesigned to use a low alloy, high-yield strength steel in order to meet the U.S. Army specifications for total weight. Plain carbon steel is used in the Universal Jeep, where weight is less critical. Low alloy, high-yield strength steel is the only type of steel employed in the Jeep that is purchased according to brand name, because no universal specification has yet been established. The carbon content is limited to about 0·15% by welding considerations, and three alloying elements are often used, for instance 0·75% silicon, 60% chromium, and 0·10% zirconium in the case of the Jeep material. This composition was the particular choice of the frame manufacturer, although Willys-Overland would have been willing to accept other analyses. The minimum physical properties obtained in these steels in thin sections are 70,000 p.s.i. tensile strength, 50,000 p.s.i. yield strength, and 22% elongation in 8 in. Requirements more difficult to measure, especially in production, are weldability and corrosion and fatigue resistance. The length of time required to test particularly the last two makes the listing of approved sources desirable.

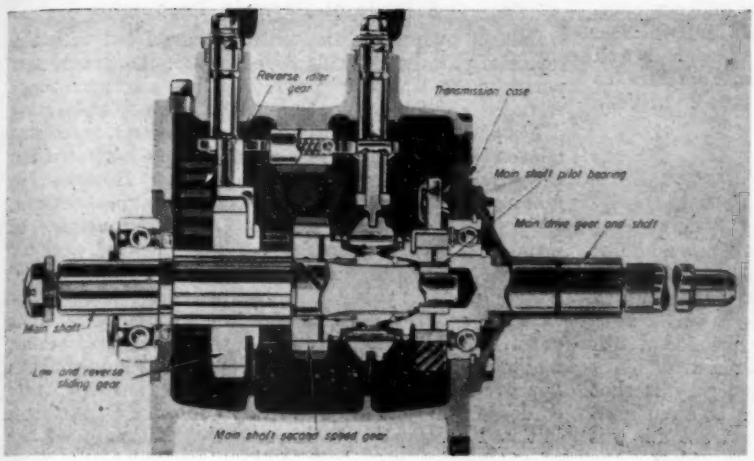
In addition to the large sheet metal parts mentioned above, the Jeep contains numerous small stampings, mostly made from hot-rolled, pickled and oiled 1008 (0·10% maximum carbon, 0·40% manganese) and 1020 steel (0·20% carbon, 0·40% manganese). The steels are respectively rimmed and semi-killed, but this is not generally specified on the drawings. One school of metallurgists uses the lower carbon steel wherever it is considered to have sufficient strength; the other school, including Willys-Overland, uses the higher carbon steel wherever it will form the part, on the grounds that the maximum stresses are somewhat indeterminate and that the production costs are not affected. Direction of grain flow is specified wherever necessary.

Castings

Three main types of castings are used in the automotive industry—steel, malleable iron and grey iron. In addition several materials, many of them proprietary, are available that border on these classifications, such as graphitic steel and pearlitic malleable iron. Only grey and malleable cast iron are used in the basic Jeep, although steel is used on some auxiliary equipment. Steel and a larger proportion of malleable iron are used in heavier vehicles, but the present materials have proven satisfactory for the Jeep even under the severest conditions of service. The main reason for this fact is that the stresses in many Jeep castings are relatively low, because the sections must be made thick enough to permit proper flow of the metal in the mold.

Intricacy of design is the usual reason for selection of the casting process. There is little prospect of replacing castings by weldments in the automotive as in the heavy machinery industry, at least as far as the lighter vehicles are concerned. Such substitutions are usually only economical in comparatively large parts. It is commonly said that grey cast iron is so brittle that it should only be used where no impact resistance is required. However, the material possesses sufficient toughness for many automotive parts, and in the remainder strength is also an important consideration for preferring malleable iron; the same is true in comparing malleable iron with cast steel. Malleable and particularly grey iron possess an important advantage over steel in their resistance to wear; the exposed particles of graphite are soon dislodged, forming pockets that hold the lubricant. Both kinds of cast iron also have the property of excellent machinability, which contributes greatly to the low cost of finished parts.

The malleable iron castings in the basic Jeep are the wheel hubs, front and rear differential housings, and brake and clutch pedals. Recently normalised forged 1141 steel (0·40% carbon, 1·50% manganese, 0·10% sulphur) has been substituted temporarily in the pedals owing to a shortage of foundry capacity and to the availability of hammer capacity. All malleable iron castings belong essentially to one grade, and have minimum physical properties in the neighbourhood of 50,000 p.s.i. tensile strength, 32,000 p.s.i. yield strength, and 10% elongation in 2 in. Chemistry is not specified in any way.



Section through the gear box.

The large number of grey iron castings in the Jeep includes the cylinder block and head, piston rings, camshaft, intake and exhaust manifolds, water pump body and impeller, oil pump body and cover flywheel, clutch housing and release bearing carrier, transmission case, transfer case housing, and brake drums. These parts fall substantially into two classes: those in which strength is not an important factor, so that machinability is the prime consideration; and those in which strength and other physical properties take precedence over machinability. In the former class only a maximum hardness in the region of 180 Brinell is specified, as compared with range of about 180–220 Brinell in the latter. Both local and overall uniformity of hardness are essential for good machinability; annealing may be required for this purpose, but this operation is at the discretion of the foundry, providing machinability and physical properties are satisfactory. Chemical analysis is specified with relatively broad ranges, since a particular composition is neither required by nor sufficient for a given application. The use of inoculants is also optional with the foundry. Occasional tests are made of the physical properties of sample test bars, including tensile strength (about 20,000 and 30,000 p.s.i. respectively), transverse strength, and transverse deflection. Micro-structure is also an excellent indication of the quality of grey cast iron, the shape, size and distribution of the graphite particles being particularly important.

Two cast iron parts, the piston rings and camshaft, differ considerably from the foregoing description. The piston rings contain about 0·35% phosphorus for greater wear resistance. The hardness is 98–106 Rockwell B (228–293 Brinell). The modulus of elasticity, which in cast iron depends on the form of the graphite particles, is controlled by specifying the force required to close the gap in the rings. The camshaft is the only alloyed casting in the jeep, for which 0·30% nickel, 0·75% chromium, and 0·50% molybdenum or 0·90% chromium, 0·50% molybdenum, and 0·60% copper are optional. The hardness is 262–293 Brinell except on the cam lifts and fuel pump eccentric, which are flame hardened to produce a minimum hardness of 65 Shore Sceleroscope (461 Brinell).

Bearings, Bushings and Thrust Washers

The most critical bearings in the Jeep, as in all automotive vehicles, are the connecting-rod and crankshaft main bearings. Prior to the tin shortage, tin-base babbitt containing 7·5% antimony, 3·25% copper, remainder tin, was used; since that time lead-base babbitt containing 15% antimony, 0·5% copper, 1% tin, 1% arsenic, remainder lead, has been substituted. It is generally agreed that the main characteristics required in a bearing metal are embedability, fatigue strength, and resistance to scoring and corrosion; wear is only a problem if these requirements are not fully met and an ample supply of clean and proper lubricant is not present. Both tin- and lead-base babbitts show excellent performance as regards all of these properties except that the fatigue strength is relatively low. The bearing metal, only about 0·005 in. thick in the finished parts, is therefore cast on to a backing strip of 1010 steel (0·10% carbon, 0·40% manganese), a construction that has proved entirely adequate. The use of a thin layer of soft alloy supported by a wrought or cast backing, often with an intermediate material for better bonding and reinforcement, represents a definite trend in the metallurgy of bearings. Unlike most aircraft-type bearing materials, both babbitts have the advantage of being usable with crankshafts journals tempered below 300 Brinell.

The Jeep piston pin is locked in the connecting rod and floats in the aluminium piston without a bushing. The pin hole of the piston is diamond-bored to a high finish and the part then tin-plated all over. The pin is ground to a fine finish and selectively fitted to the piston. These details contribute greatly to the success of the design.

Ball and roller bearings used in transmitting the power to the wheels and in the wheel bearings are stock items, the metallurgy of which has been developed by the bearing manufacturers. In some bearings the races and balls or rollers are made from 52100 steel (1·00% carbon, 1·35% chromium), hardened and tempered to a minimum of about 60 Rockwell C. In the remainder these parts are made from 4620 steel. (0·20% carbon, 1·75% nickel, 0·25% molybdenum), carburised, hardened, and tempered also to a minimum of about 60 Rockwell C. During the war 4720 steel (0·20% carbon, 1·00% nickel, 0·50% chromium, 0·20% molybdenum) was formulated specifically for these applications and successfully substituted.

Bronze containing 10% tin, 10% lead, remainder copper, is used in the most highly stressed cast bushings such as the front wheel bearing spindle and transmission countershaft bushings. The latter was used only in the military jeep, being replaced by needle bearings in the larger transmission of the civilian model. Sintered bronze containing 10% tin, remainder copper, is used in the clutch shaft and Bendix starter pilot bushings. A drawback of sintered metals for some high-duty applications, such as spring shackle bushings, appears

to be their lack of resistance to crushing under impact. The crankshaft thrust washer is made of 1045 steel (0·45% carbon, 0·75% manganese), hardened and tempered to 207–255 Brinell. Other thrust washers, as in transmission, transfer case, and front wheel universal joints, are made of bronze.

Surface Treatments for Strength and Wear Resistance

Some of the most important of recent developments in metallurgy include surface treatments of three kinds: those which increase fatigue strength by means of compressive residual stresses on the surface; those which reduce wear by pitting or roughening the surface so as to hold the lubricant; and those which provide a soft coating with superior wearing-in characteristics.

The principal method in the first category is shot peening, which during the war was applied to an increasing amount of material. Parts of the Jeep treated in this manner are the valve springs, the tension sides of the two upper leaves of each chassis spring, and the yokes of the Tracta front axle universal joints. In the case of the springs, for example, the intensity of peening is specified as 0·012–0·015 A2, meaning 0·012–0·015 reading on No. 2 Almen Gauge, using the "A" Test Strip. The lives of all three types of parts were increased several hundred per cent. by this treatment. It is interesting to compare this method, which leaves a roughened surface, with the use of polishing and superfinishing to increase fatigue strength by eliminating stress raisers. A method that has some peening effect and at the same time provided any desired degree of finish is Vapour Blasting, in which a jet of abrasive sand or crushed rock suspended in a water emulsion is directed under high pressure against the surface. Sandblasting used to clean forgings has a peening effect to a minor degree, but is chiefly preferred to pickling for other reasons. Nitriding is a chemical means of obtaining a compressed surface, though this is not the only reason for its use.

The way in which the pitted surface of cast iron serves to hold the lubricant and reduce wear has already been described. Shot-peened surfaces also possess this property. However, another method is used in the Jeep to maintain a film of grease between the flat sliding surfaces of the Tracta front wheel universal joints, namely the formation of a complex phosphate coating by means of the Parco Lubrite process. Still another method is hard chromium plating, which in the Jeep is applied to the shock absorber piston rod and carburettor throttle valve shaft. A variant of this process is the Van der Horst method, in which the current is reversed after plating, so that the fissures in the surface of the plate are enlarged. This method has proved beneficial in some engines when applied to the piston rings or cylinder bores, but the full scope of its application has yet to be determined. The limit in treatments of this kind is reached in sintered and sprayed metal coatings, which are sufficiently porous to hold reservoirs of lubricant.

The tin plating of the aluminium pistons in the Jeep has already been mentioned as an example of a surface treatment for breaking-in purposes. Tin is also applied to some of the piston rings, while others are coated with phosphates. The other metal applied for this purpose is copper, which in the Jeep is used on the cam of the steering gear.

Salvage of Parts in Production

Salvage operations are generally associated with the repair of parts worn or damaged in use. However, new parts in the course of production are also sometimes salvaged, chiefly in order to repair casting and machining defects. Until recently the amount of such salvage was relatively small, since other remedies were sought if the percentage of scrap became excessive. However, in many types of parts the war occasioned severe shortages, which were accentuated by the increased volume of scrap due to the large number of inexperienced workers. Manufacturers still differ as regards the extent they salvage parts in production, but little question remains that this practice is permissible where justified by costs or lack of material, providing that the applications, methods, and control of repair procedures have been approved on the basis of performance tests or other evidence. In 1944 the U.S. Army Ordnance Department initiated a campaign to increase the legitimate salvage of automotive grey iron castings, which at that time were critical. Better understanding between prime contractors, foundries, and Ordnance inspectors was sought by having written approval from the prime contractors and Ordnance Department for permissible locations and methods of repair. The S.A.E. War Engineering Board co-operated in the project, which included the preparation and publication of recommended procedures. The acceptable processes, together with their limitations, were described in some detail, and comprised arc and gas welding, nickel arc welding, brazing, silver brazing, soldering, plugging, bushing, peening, sealing and rusting. Parts of the Jeep for which repairs were approved in certain non-critical areas are the transmission case and cylinder block and head; the remaining castings are too small to justify salvaging. The net effect of the campaign was to prevent improper repair, increase the production of satisfactory parts, and eliminate disagreements between the various parties concerned. Consequently a similar project for the salvage of steel and malleable iron castings was later undertaken by the Ordnance Department and War Engineering Board, but did not apply to the Jeep because these castings also are too small to warrant salvage.

Repair of small machining defects in low-stressed parts of the crankshaft were approved by Willys-Overland and the Ordnance Department after exhaustive dynamometer tests of sample parts. As in the case of the Jeep castings, details of the approved procedures—hard chromium plating and atomic hydrogen welding—were specified on the drawing. Early in 1945 the Ordnance Department started yet another general salvage campaign, namely for use of hard chromium plate, but the need for this has been eliminated by the ending of the war. Hard chromium plate offers the advantage of better wear resistance than even the original part, but is expensive and should be used with considerable discretion as regards procedures and applications.

Acknowledgment

The writer wishes to express his gratitude to Willys-Overland Motors, Inc., for permission to publish this article, and in particular to Mr. Delmar G. Roos, Vice-President in Charge of Engineering, under whose guiding hand the successful applications of and policies regarding engineering materials were developed.

Aluminium Alloy Scaffolding

By G. O. Taylor, M.S.E., A.I.P.E., F.Inst.P.I.

With the increased availability of aluminium the trend of applications is increasing and, although common sense demands that its alloys should be used which their advantages warrant, standard alloys, in various finished and semi-finished forms, are more readily obtained than many other materials, it is not surprising that attention should be directed to their use for tubular scaffolding. The recent reduction in the basic price of aluminium will undoubtedly influence the choice of this material for that purpose.

IN post-war building development there is a marked tendency to employ aluminium alloys in many applications where other materials were previously used. Not only are light metals being specified for complete prefabricated houses, but also for various parts such as window frames, gutters, sills and other fitments.

This tendency results largely from a better appreciation of the outstanding characteristics of light alloys due to their extensive use for war-time purposes during the past few years and the realisation that aluminium alloys are not only light, but strong, and can replace traditional materials with definite advantages in many cases.

The urgent demand for all types of buildings coupled with the labour shortage renders it imperative that any labour-saving scheme should be carefully considered, and it would seem that a definite case can be established for the more extended use of aluminium alloy tubular scaffolding and fitments to assist in the speeding-up of building operations.

Piece for piece aluminium alloy scaffold tubing is only one-third the weight of steel tubing and can thus be handled with a fraction of the expenditure of effort needed with the heavier material. Erection is not only quicker but transport from place to place on the building site can be accomplished easily and at less expense—*i.e.*, to carry out the same work it is necessary to use about one ton of aluminium alloy instead of three tons of steel.

The facility with which light alloy scaffolding can be erected due to its lightness, is further enhanced by the absence of the rust and scale occurring on steel scaffolding after it has been in use for some time. Aluminium alloys are much more resistant to atmospheric corrosion than is steel and tubes and fittings slip readily together. The comparative resistance to surface corrosion of the two metals can be visualised if it is recalled that the statue of "Eros" in Piccadilly Circus is made from aluminium alloy and unprotected in any way it has satisfactorily withstood atmospheric action for over half-a-century. The condition of the statue had it been made from unprotected steel and left exposed for 50 years can easily be imagined.

If it is conceded then that from the point of view of weight and resistance to corrosion, light alloy scaffolding offers decided advantages, let the question of strength be considered. This is important, as from a purely theoretical viewpoint it would appear that aluminium alloy tubes are at a great disadvantage when compared with steel tubes of the same diameter and wall thickness.

In considering this question it must always be borne in mind that the loading of a scaffold structure is due largely to the weight of the structure itself and that the imposed loads such as men, bricks, mortar, etc., are usually small in comparison. Since aluminium alloy tubing is only about one-third the weight of steel, a straight substitution of light alloy for steel reduces the loading due to structure weight to about 35% of its original value.

It may in fact be possible to reduce this figure still more as Northern Aluminium Co. Ltd., have carried out a series of practical loading tests which would indicate that the stresses arising in practice do not approach a critical value, and it would appear that the wall thickness of standard steel tubes as at present used is dictated by considerations of facility in production and consequent price, rather than by strength requirements.

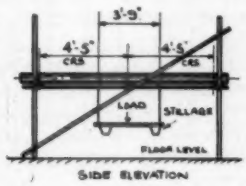


Fig. 1.

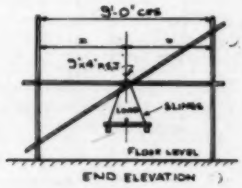


Fig. 2.

Method of measuring deflection under load.

Actually, aluminium alloy scaffolding built from Noral 62 ST alloy tubing has been in use for some time by building contractors who have proved in everyday practice that the theoretical disadvantage which would appear to arise in the comparative resistance to column loading has no significance and that the advantages of weight reduction and resistance to corrosion are fully realised. It is also worth noting that the Noral 62 ST tubes stand up well to rough handling and do not suffer any greater incidental damage than occurs with steel.

The series of loading tests carried out by Northern Aluminium Co. Ltd., are of considerable interest and by courtesy of this company the author has been allowed to reproduce the results obtained.

Light Alloy Tubing

The aluminium alloy tubing used in the tests was Noral 62 ST alloy. This is a heat-treated alloy and the minimum mechanical properties specified in D.T.D. 460 are :—

0·1% *Proof Stress* in tons/sq. in., 18 (min.).
Ultimate Tensile Strength in tons/sq. in., 22 (min.).
Elongation % on 2 in., 6 (min.).

The outside dia. of the Noral 62 ST tubing used throughout the tests was $1\frac{23}{32}$ in. and the inside dia. $1\frac{1}{4}$ in. A 12 in. length of this tubing weighs only 1·23 lb. against 3·32 lb. for identical steel tubing.

Couplings

Preliminary trials were carried out with different types of couplings and it was found that the most suitable for use with light alloy were :—

(*a*) Standard right-angle couplings with hinged bolts.
(*b*) Standard cam-lock couplings.
(*c*) Standard swivel couplings.

The band and screw type coupling is not so satisfactory for use with aluminium alloy scaffolding as the locking screw dimples and distorts the tube.

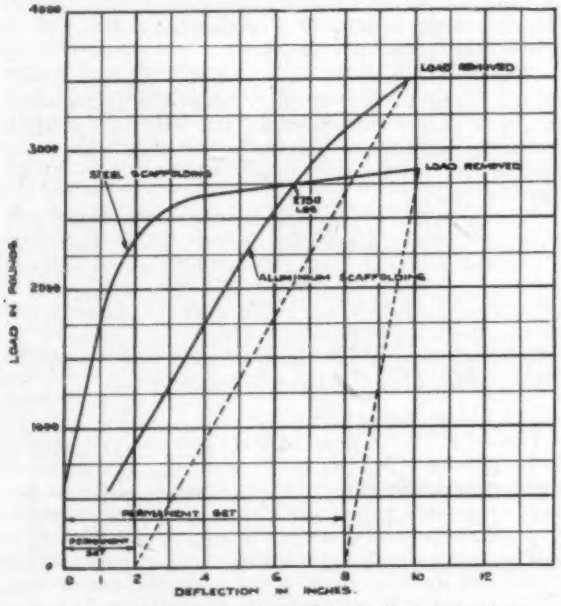


Fig 3.—Maximum loadings for similar deflections in aluminium alloy and steel tubing.

Test No. 1. (See Figs. 1 and 2)

For the purpose of accurate comparison of the behaviour of identical structures in Noral 62 ST alloy and steel under direct loading, structures as illustrated diagrammatically in Figs. 1 and 2 were erected alongside each other and the deflections measured under load conditions. The structure as erected in Noral 62 ST alloy using standard swivel couplings and right-angle couplings with hinged bolts weighed only 253 lb. against 565 lb. for the steel erection. The total initial loading in each case was 623 lb. derived from : (*a*) 9 in. × 4 in. rolled steel joist 235 lb. ; (*b*) Stillage 342 lb. ; (*c*) Slings 46 lb. The actual deflections recorded were as given in Table I.

Fig. 3 shows graphically the maximum loadings attained for similar deflections in Noral 62 ST alloy and steel and the amounts of permanent set recorded on release ot the load.

It is interesting to note from these figures that while steel is more resistant to initial deflection it yields very suddenly to give a large deflection for a small increase in load, whereas the Noral 62 ST alloy yields proportionately and actually requires approximately a one-third greater load to give the same degree of ultimate deflection acquired by steel. In this test it should particularly be noted that after releasing the load of 3,535 lb. from the Noral 62 ST structure the permanent set was only 2 in.

TABLE I.

Load in lb.	Noral 62 ST alloy Deflection in inch	Steel Deflection in inch
Nil	0	0
623	1⅛	0
735	1⅛	⅛
847	1¼	⅛
959	2¼	⅜
1,071	2¼	⅜
1,183	2⅜	5/16
1,295	3	5/16
1,407	3¼	⅜
1,519	3¼	⅜
1,631	3½	½
1,743	4	½
1,855	4⅛	1⅜
1,967	4⅜	1⅜
2,079	4½	1½
2,191	5	1⅝
2,303	5⅛	1⅝
2,415	5⅜	2⅛
2,527	5½	2⅛
2,639	6¼	3⅛
2,751	6⅜	6¼
2,863	7	10¼
2,975	7⅛	Test discontinued
3,087	7½	
3,199	8⅛	
3,311	8½	
3,423	9¼	
3,535	9½	

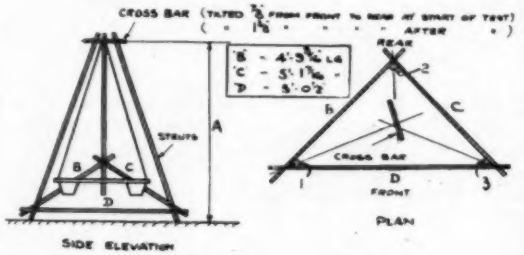


Fig. 4. **Fig. 5.**

Testing a tripod structure.

against 8 in. for the steel structure after release of the load of 2,863 lb.

Test No. 2

A tripod structure as shown in Figs. 4 and 5 was erected in Noral 62 ST alloy tubing using standard swivel-lock couplings and subjected to loading tests. In this test the weight of the stillage and slings prior to loading was 448 lb.

Load in lb.	Height at "A" ft.	in.	Horizontal Deflection Strut 1 in.	Strut 2 in.	Strut 3 in.
448	8	6¼			
1,120	8	6⅝			1/16 (I)
1,904	8	6¾		1/16 (O)	
2,576	8	6¾			⅛ (I)
2,688	8	6¾			
3,472	8	6⅞			
4,144	8	6		1/16 (R)	⅛ (R)
4,816	8	5⅞			
5,152	8	5⅞			
5,600	8	5¾	⅛ (R)	⅛ (R)	
5,824	8	5⅝	1/16 (R)	1/16 (R)	⅛ (R)
5,936	8	5⅝			
6,160	8	5¼			3/16 (R)
6,496	8	5⅛			
6,720	8	5⅛	⅛ (I)		
6,944	8	5⅛	⅛ (R)		
7,280	8	5⅛			
7,448	8	5⅛			1/16 (R)

R.—Deflection to rear (see sketch)
I.—Deflection inwards " "
O.—Deflection outwards " "

When the weight was removed, the struts returned to normal.

Test No. 3

In this test a typical bricklayers' wall scaffolding as shown in Figs. 6 and 7 was erected and submitted to various loads of bricks as would occur under normal working conditions. It will be noted that deflection under load was of no significance.

Light Alloy Clamps and Couplings

A suitable aluminium alloy can be used with advantage to replace clamps and couplings at present made from malleable iron, and as such clamps are required urgently in large quantities production times can be cut down by use of the gravity die-casting process which produces dimensionally accurate castings at a high rate of output.

Fig. 6.

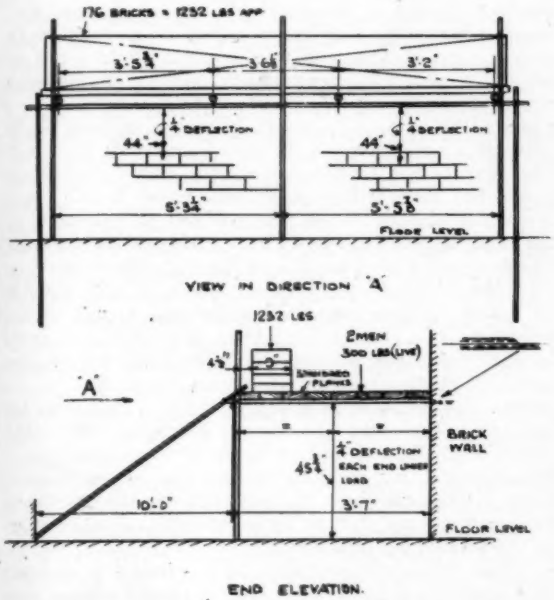


Fig. 7.—Test on bricklayers' wall scaffolding.

Experiments on the production of proprietary types of clamps have been carried out in the foundries of the Northern Aluminium Co. Ltd., using different alloys. As a result of this investigation it has been ascertained that Noral 226 alloy fully heat-treated in accordance with Specification D.T.D. 361 is a suitable metal for the purpose. Clamp castings in this alloy have an ultimate tensile strength of 23–24 tons/sq. in. with an elongation of about 1·5%.

Tested in comparison with the same designs of clamps in malleable iron it was found that the screw threads stood up to their work extremely well and that the light alloy casting was in general stronger than malleable iron.

By taking advantage of the specific design characteristics of the aluminium alloy and carrying out slight modifications such as thickening up the boss of the clamps to allow for non-central drilling such light-weight clamps have considerable advantages not only in strength combined with lightness but also in finish and resistance to corrosion. When used in conjunction with light alloy tubular scaffolding it is advantageous to have pointed Allen screws in the clamps rather than the usual cup end screws as these " bite " to minimise slipping on the smoother surface.

The first cost of aluminium alloy scaffold tubing will admittedly be two to three times as much as that of steel, though the price difference between aluminium alloy and malleable iron fittings is very much less. It is contended, however, that the difference in purchase price will in a very short time be more than balanced by the advantages and economies arising from lower transport charges, lower erection costs, lower maintenance charges and greater scrap value of the scaffolding at the end of its useful life.

Science and the Steel Industry

Presidential Address

THE labour of a host of men, of great laboratories and long patient research, build up the sound structure of knowledge and contribute to progress. Often progress appears to be slow, but the addition of fact to fact, just as a building proceeds brick by brick, may result in a revolutionary discovery. It is this research which is the essential basis of industrial progress and approach must be made scientifically so that there will be no confusion in building up the facts. This was emphasised by Dr. C. H. Desch in his Presidential Address at the recent annual meeting of the Iron and Steel Institute when he discussed the subject of science in the steel industry.

Dr. Desch reminded members that it was in this country that the Industrial Revolution first took place in the eighteenth century; it was here that iron and steel works were put into operation and industrial towns grew up while the Continent and America were still in the agricultural stage; it was here that new processes —the production of crucible steel, rolling by grooved rolls, puddling, the use of hot blast, the Bessemer and open-hearth steel processes, and basic working— were invented and applied. It was here, too, that the scientific foundations of steel metallurgy were laid by Lowthian Bell, Sorby, and many others. On the problem of reconversion from production for war to normal conditions, he emphasised that the planned replacement of plant which falls short of the high standard of efficiency set by the best of the establishments under scientific control is one of the immediate tasks. Fully integrated plants, working on a large scale and handling their materials from the mine to the finished product, have shown their advantages, and in spite of the enormously high capital costs it is certain that they will constitute a very large proportion of the industry. But the small specialised works, employing highly skilled men on some important product of which the total tonnage is small, still has a place in the national economy, and to the student of industry the study of these relatively small undertakings, depending for their existence largely on a traditional standard of craftsmanship, has a fascination of its own, and the importance of such small industries is out of proportion to their size.

In dealing with the services science can render to this important industry, Dr. Desch gave a brief outline of organised research work in metallurgy from the first World War and referred to the Research Associations

formed in accordance with the schemes of the Department of Scientific and Industrial Research ; and of the Committees formed by this Institute. In concluding his references to the Research Committees, he paid tribute to Dr. Hatfield and Dr. Swinden for their share in fostering them in their early stages, in securing the willing co-operation of so many industrial firms and academic departments, and in placing at the disposal of the several committees their own wide experience of the industry. Without their help progress would have been far less rapid. Their comparatively early deaths, like that of one of our ablest investigators of corrosion, Dr. Bengough, must be attributed to the additional strain which they bore during the war years.

On the question of trained staffs, he considered that however complete the planning of an organisation for applying science to an industry may be, it depends for its success on the quality of the investigators whose services it can command. Moreover, success in applying the results of research to industrial practice depends on the capacity of departmental managers and others—not excepting chairmen and managing directors—for appreciating and estimating at their true value the conclusions presented to them by the research workers. Hence the importance of the subject of the supply of trained metallurgists. The supply of men with the requisite training and with the ability to take positions of responsibility is insufficient and apart from graduating from a university he outlined the steps which have been taken to establish means of obtaining a qualification in metallurgy.

Metallurgy, as Dr. Desch pointed out, is not a fundamental science. In so far as it is a science at all, it consists in the study of physics and chemistry as applied to the special class of metallic substances. It existed as an art thousands of years before it was furnished with a scientific basis, and in some branches the skill of the experienced manual worker still counts for much. But the days when fuel economy and speed of production were not vital have passed, and scientific knowledge becomes more and more essential to production. We increasingly make use of refined methods of control, often depending on physical phenomena unknown at the beginning of the century.

But in considering the value of a scientific approach to the problems of the steel industry, the question is sometimes asked: Can we make use of the deeper knowledge of the nature of metals and of the constitution of metallic systems which we now possess, to predict the properties of a given metal, or to devise new alloys to give a desired combination of properties ? Dr. Desch thinks that an affirmative answer can be given, although much remains to be done. It is stated that Taylor and White made more than 50,000 experiments before arriving at the best composition and heat-treatment of the high-speed tool steel which created a sensation at the Paris Exhibition of 1900. For a long time further development of tool steels was on empirical lines, a little of first one element and then another being added, rather on the principles of a cookery book, until improved properties were obtained. Now, largely owing to the use of the method of isothermal transformation (that is, of heating to a high temperature and then cooling to some temperature which is maintained constant for a sufficient time, the process being repeated on other specimens at different temperatures) it has been possible to analyse the separate effects of various alloying elements on the rate of transformation on which hardening and softening depend.

In the course of the war it was discovered that we had allowed ourselves an extravagant luxury in the number of different compositions of alloy steels for engineering use and a drastic revision led to the number of specifications being reduced from 3,000 to 83, with resultant great economy of material.

In discussing the practical object of researches to improve quality in the products of manufacture, Dr. Desch referred to keeping a careful record of every consignment of a certain product of a works (such as rolled strip), the composition and manufacturing procedure being kept as constant as is practicable, on plotting the values of a specific property, such as tensile strength or ductility, a frequency curve is obtained. The bulk of the results will cluster about some mean value, but there will be some falling well below it and some well above. Good practice will be indicated by the small amount of spread on each side of the maximum. The fact that some points lie on the high side shows that, with the materials and processes available, it is possible to reach qualities superior to the general run of the product. The reasons for failure to reach the average can often be found without difficulty—some irregularity in the working of a furnace, an accidental defect in a rolling mill, &c.—but the exceptionally high results are less easily explained and deserve intensive study. The aim of scientific control in a works is not only to narrow the area of this probability curve, that is, to obtain a more uniform product, but also to shift the maximum to higher values, that is, to improve the average value of the property considered.

What the economic future of the industry at home and abroad will be, it is impossible at this critical time to predict. One thing is certain : there will be no room for inefficiency. If the manufacture of iron and steel in this country, with the high cost of coal and the necessity for importing so much of the raw materials, is to succeed, both the equipment and the direction of our works must be of first-class quality. No skill in finance can take the place of efficient technical direction, and we must look forward to trained metallurgists with the solid background of a good general education assuming an increasing share in the management of the great undertakings which will comprise the major part of the industry.

Thread Grinding Machine

THE accurate and rapid grinding of Whitworth and other screw threads has become an economical and time saving operation as a result of the introduction of the Churchill thread grinding machine. On general work, either hardened or soft, output is equivalent to that of four or five screw cutting lathes and with the great advantage that threads are produced in accurate relationship with other surfaces on the work. For this purpose the face of the grinding wheel is shaped by a crusher roller, the face of which is formed to the shape and pitch of thread required. This direct, efficient and extremely accurate method supersedes the elaborate forming devices and heavy diamond expanse previously necessary for thread grinding. A well illustrated booklet giving useful information and working data concerning this machine is available from The Churchill Machine Tool Co. Ltd., Broadheath, near Manchester.

The Patent Act

By S. T. Madeley

The amendment to the Patent Act which the author summarises in this article has now been accepted by Parliament.

TAKING a period which ended just as the shadows of the approaching World War II began to encroach upon the world, that is to say, 1931-35, the total number of British Patents granted for alloys was about a thousand. This is an important number.

It is of crucial interest to patentees and others connected with metallurgy to learn definitely what are the intentions of the British Government with regard to extensions of term of such patents as may have been inadequately remunerated because of the hostilities, and also what is going to happen to enemy-owned patents and patent applications. These and kindred matters are dealt with in a Bill which has now been read in Parliament, and relates to amendment of the Patent Act. It is the outcome of long and earnest consideration given to the matter by the Departmental Committee on Patents appointed by the Board of Trade, and generally known as the "Swan" Committee. Much evidence, both written and oral, was placed before it. A lot of material is not touched by the present Bill, and will no doubt be the subject of subsequent legislation.

According to the Bill, which will now be summarised, a new subsection 8 is going to be added to section 18 of the principal Act. Under the present subsection 6 an extension of patent term can be granted on the sole ground of loss or damage due to hostilities, though subsection 7 limits to 10 years the total extension. As the Act now stands, application under subsection 6 is made to the Court by way of Originating Summons. The new subsection will give the patentee an option to apply to the Comptroller without the necessity of prior advertisement of the intention to apply. The Comptroller will have the option of sending the case to the Court, if he thinks it more suitable for decision by that Tribunal. There will be an appeal from the Comptroller's decision to the Patents Appeal Tribunal.

The grounds on which a patent may be revoked are set out in section 25 of the principal Act. A paragraph is to be added to this section, which will strengthen the hand of the Government.

It adds a new ground which consists in the secret working of an invention, prior to the date of the patent, by a Government Department or anyone authorised by it, otherwise than in consequence of direct or indirect communication or disclosure of the invention to a Government by the patent applicant.

In cases in which an application has become abandoned, publication of the specification, drawings, etc., is prohibited. Such publication is, however, to take place where the application for a patent has been abandoned or become void, or an application for a design has been abandoned or refused, during the war, and the Comptroller is of the opinion that the application was made by or on behalf of a German or Japanese National, or a German or Japanese company.

Provisions are contained in section 91C of the principal Act relating to communications of inventions and designs under agreements or arrangements with other countries. According to the new section 91C, communication of this kind, or publication, making use, exercise or vending of the invention or the publication or application of the design which takes place because of such publication, is not to prejudice an application for a patent or registration of a design when it is made by a person from whom the invention or design was communicated or his legal representative or assignee, nor shall it invalidate the grant of patent or registration of the design resulting from such an application. The application in question, furthermore, is to have priority over any other application for a patent or for the registration of a design as regards either a whole or a part of the invention or design if the other application was made by someone who obtained the invention or design, either as a whole or in part, as a result of the communication in question. In addition, obtaining of the said invention or design as a consequence of the communication in question is to be a ground for refusal of the application or for a revocation of the patent or cancellation of the design, as the case may be.

The communication aforesaid may be presumed to have given rise to the said publication, and so on under circumstances and subject to conditions and exceptions to be prescribed in the rules.

Such powers as the Board of Trade is able to exercise on behalf of those from whom inventions or designs have been communicated by the Government of another country to the United Kingdom Government are only to be exercised to the degree that the Board of Trade is satisfied as to substantially equivalent legal provision having been or being made by that country on behalf of those from whom inventions or designs have been communicated by the United Kingdom Government to the Government of that country.

According to section 6 of the Patents, Designs, Copyright and Trade Marks (Emergency) Act, 1939, the Comptroller is empowered to extend the time for performing any act such as paying patent renewal fees or filing documents, where delay has been due to the war. Under the Bill he is to be able to refuse to exercise these powers on the sufficient ground that (*a*) the act in question, if done when it should have been, would have been done by or on behalf of a German or Japanese National or Company, or (*b*) the National or Company in question is of a country that does not to the Comptroller's satisfaction exercise substantially equivalent legal powers to those under the said section 6 on behalf of British Companies or Nationals.

The Comptroller will be enabled to refuse an application for patent grant or design registration on the sufficient ground that the invention or design was invented or designed in Germany or Japan by a German National in enemy territory between 3rd September, 1938 and 31st December, 1945. This will also be able to be used as a ground for opposition under section 11, or for revocation under section 25 or 26, or for cancellation of a design registration under section 58, or for rectification of the register under section 72 of the principal Act. Furthermore, it will be available as an

additional defence on infringement proceedings, or for a counter claim for revocation of a patent or for cancellation of a design registration.

Exception is, however, made where it can be proved that the inventing or designing was done in Germany before 3rd September, 1939, or in Japan before 7th December, 1941, and has not since then been in whole or in part beneficially owned by a German or Japanese Company or National. Another exception is made when it can be proved that the invention or design was independently invented or designed outside Germany or Japan by someone not a German or Japanese National, through the applicant, patentee or proprietor claims, before the inventing or designing took place in Germany or Japan or by a German National in enemy territory.

An appeal will lie from the Comptroller's decision to the Patents Appeal Tribunal. The applicant for a patent or a design may be required to provide relevant information.

Amongst other definitions given in the Bill is that of Germany, which is stated to be territory comprised in the German State on 1st March, 1938. Another is that of German National which is stated not to include anyone who was a German National simply because of the incorporation of the relevant territory in the German State after 1st March, 1938, or was not an enemy under the Trading with the Enemy Act, 1939.

Research Organisation in the Iron and Steel Industry

By Sir Charles Goodeve, O.B.E., D.Sc., F.R.S.
Director, The British Iron and Steel Research Association.

Opinions differ on the best method of restoring the position of the British iron and steel industry to that pre-eminence necessary to the prosperity of this country, but not on the part research must play. In a recent address to the Newport Metallurgical Society, Sir Charles outlined certain aspects of the research organisation in the industry which he presented under three main headings : competitive research in special products : co-operative research : and independent academic research. He directed particular attention to the importance of proper interrelations of the various forms of research so that their cumulative effect could be applied to the improvement of the industry as a whole. His address, in a somewhat abridged form, is given in this article.

THE high technical position of British steel in the last century is unquestionable, and arose through the enterprise of those who inhabit this island and to their then good natural resources to meet the great demands of an expanding industry. The reputation of British steel still persists throughout the world. However, the first quarter of this century saw the great expansion of the American steel industry with which at first perhaps we failed to keep pace, but so great an advance was made in the ten years before the recent war that this leeway was almost made up. The six years of war with the consequent standstill of plant building and the diversion of research facilities to immediate war problems made us again fall behind. It is remarkable how many people fail to appreciate that such weaknesses in the iron and steel industry as now exist are almost entirely due to the war. But our objective is quite clear—we must have in this country better qualities of steel at equal or less cost than anywhere else in the world, and we must be the first to introduce new steels, new processes, etc., just as we are generally the first to discover them. Only by achieving this can the iron and steel industry make its expected contribution to the prosperity and happiness of every man, woman and child in this country.

Fortunately, we have on the research side, as well as on other sides, a strong basic organisation to put this matter right. Most of the major steelmakers of this country have well equipped and staffed research and design laboratories and some of these are outstanding. Their natural pre-war expansion, held up for six years, is in full swing again, and before long their total size will be double the 1939 level. The importance of works' research laboratories striving to maintain the competitive position of the various products of the industry remains unchallenged even in this present revolutionary age, in which co-operation is such a popular word. We also have great strength on the academic side, although here, as in many other parts of our nation, we are faced with the need for considerable expansion.

Co-operation Research

I should like, however, to deal in some detail with co-operative research because that is the key word of the Research Association movement. The main part of my remarks will be confined to co-operation between firms in the iron and steel industry, but there are other important types of co-operation which will be referred to later.

Co-operation in the iron and steel industry goes back a very long way to the founding of the Iron and Steel Institute and of many local metallurgical and engineering societies in the last century. These provided means by which people got together and discussed their experiences. It was, however, limited by the competitive atmosphere of the times. A significant step was taken during the 1914–18 war when various committees were set up under the Iron and Steel Institute to investigate certain problems which were troubling the industry as a whole. However, most of these committees died with the end of that war.

Soon after 1918 an important event took place in another direction—the executives in the steel industry got together and set up the National Federation of Iron and Steel Manufacturers to tackle some of their major common problems. Before very long those concerned realised that the firms' common commercial problems were intimately related to their common technical problems. They therefore provided one of the

prime needs of research, whether co-operative or otherwise—money. They set up a Fuel Economy Committee and research group.

A great event occurred during the latter part of the recent war. On the advice of the D.S.I.R. and in consultation with the Institute, the Federation set up an autonomous body, the British Iron and Steel Research Association, the Federation undertaking on behalf of the industry the provision of the basic funds. The research activities of the Industrial Research Council and of the Joint Committees of the Institute, together with those of another small but active party in South Wales, became embodied in the new organisation on January 1, 1945. Now we have a body with the finance and the power to take us further along the road of co-operation. It will do this not only in conjunction with its parent bodies, but also with many other bodies including older research associations such as the British Refractories Research Association, British Non-ferrous Metals Research Association, British Cast Iron Research Association, British Coal Utilisation Research Association, etc.

Thus we now have three closely linked, yet autonomous bodies, serving the iron and steel industry and the people in that industry, the Federation, the Institute and the Research Association. Between them they are intended to cover all the required fields of co-operative activity. Broadly speaking the Federation propounds the policy and provides a machinery for giving effect to it, the Institute provides for the technical interests of the men in the industry and the Research Association the technical and research needs of the industry itself.

One of the main functions of the Research Association of course is to carry out research, and the first question is how does this research fit in with that carried out by the Universities, by the laboratories of member firms and by other research associations and organisations such as the National Physical Laboratory. It is concerned primarily with background or objective research and with new techniques, processes, etc., of common interest. It will prefer to support fundamental research in the Universities rather than do such work in its own laboratories, unless, of course, there are special reasons to the contrary. Also, in general, it will expect the firm's own laboratories to carry technical developments through to the applied stage, to carry out works' investigations, etc. It is obviously extremely important in our national set up that we should somehow arrange that the present enormous gap in time between the discovery of new scientific knowledge and its application is reduced considerably.

I think it is now well recognised that the extension of co-operative research activity in the Research Association does not reduce the need for research laboratories in firms' works, but indeed increases this need. These three types of organisation, the University, the Research Association and the works' laboratory act in series not in parallel. The setting up of a research association should partly eliminate a bottle-neck in the middle, but unless works' laboratories are also increased we will run into a further serious bottle-neck at the end when application of research begins to produce commercial results.

The development of steels for high temperatures is an important field in which Britain leads the world. She has made her technical advances largely by competitive research in works' laboratories. However, these laboratories are outreaching the background knowledge and have not the time nor facilities to gain it. This background will be obtained first by pooling some of the existing knowledge through the Research Association and then undertaking the missing experiments necessary to complete the picture. With this broadened base of knowledge, competitive research in works' laboratories will carry British high temperature steel to greater heights of technical achievement.

The Research Associations excursions into the applied field will be mainly on problems of wide application, such as treatment of sinter, improved port design in open-hearth furnaces, closer tolerance cold strip, etc.

On the question of general distribution of research we have decided, at least at this stage, not to attempt to centralise the research work of the Association in any one laboratory, but rather to continue the policy of the parent bodies of using all the existing research facilities in the country, supplementing these where efficiency demands it by special groups or research stations dealing with certain fields. This policy is in accordance with one of the great lessons of the war and of government research in peace time, that centralised research suffers from a great many disadvantages which more than offset the advantage of simplified administration.

The outside existing facilities that we will use can be listed under three headings, University laboratories, other research association or research institute laboratories and works' laboratories. Obviously the research contracts that we will put to Universities will be either for pure fundamental research in metallurgy or for background research in special topics. The contracts we make with firms will be largely for operational investigations or for development work of new processes of general interest to the industry as a whole. In addition, I expect firms will throw into the pool of the Research Association the results of work carried out on their own initiative, as they have done in the past.

It is obvious that the bulk of our work on refractories will continue to be put to the British Refractories Research Association, our work on coke to the British Coke Research Association and so forth. In these cases our task as a Research Association will be to ensure that the iron and steel industry's problems are specifically dealt with in the research work in these "allied" Associations, and that the results are applied.

Application of Research

I should like now to turn to a very important side of the Research Association's activities. It is one of our primary objectives to provide a mechanism whereby the brains of the people in the Industry (and outside in Universities, etc.), can be applied to the benefit of the whole of the industry as well as to that of the particular firm in which they work. We have had a number of ideas as to how to achieve this, but it is a problem which will require continuous study, and the help of everyone in the Industry, in order that we can arrive at the best solution. I can only outline here a few of the plans that we have in hand.

First of all we have set up in close relation with the whole of the research work of the Association a system of committees and sub-committees. Membership of these committees implies an obligation to apply one's knowledge to the benefit of the whole of the Industry. Many of these committees have, of course, existed for a very long time as I have already indicated, but it is, nevertheless, to me a very satisfactory omen for the

future success of the steel industry to see the frank and open discussions which take place in these committees and the general spirit of co-operation.

The second mechanism is to provide a system of confidential publications whereby the new equipment, processes, etc., developed by individuals in particular works can be fully described and brought to the attention of all others in the industry who might be able to make use of them. Anyone going around visiting works as I have done will be struck by the fact that many firms have equipment or experiences in particular parts of their works which are remarkable advances on the average found in most works. It may be a new type of mud-gun, a new use of a control instrument or a new method of working a furnace charge. It is important to get these widely known and criticised by other people, not only to improve the overall efficiency of the industry but for the benefit of the originator of the idea himself. Writing-up a new development or experience is, of course, an important factor in clarifying in the mind of the writer, exactly what he is driving at, and the comments that he will receive from other people will either strengthen his conviction in the importance of his conclusions or lead him to improve them or modify them in one way or another.

There are, of course, other ways of meeting our objective such as by conferences and discussions, and here we shall work closely with the Iron and Steel Institute. I should like to emphasise, however, that by committees, papers or conferences we shall only partly succeed in tapping the brains in the industry for the benefit of the whole. I hope we shall reach a state when every man in the industry feels that he is part of the whole, as well as part of his firm ; and that, whether or not he is on a committee or has an opportunity to speak at a conference, he will, through responsible officials in his firm, put forward to us ideas which he considers may be of wide interest.

Equipment and Raw Material

I should like to deal with two other important types of co-operation in research. The first is co-operation with the suppliers of equipment and raw materials to the iron and steel industry and also co-operation with the users of iron and steel, the product of our industry. It is difficult for me as yet to assess the degree to which that co-operation already occurs. I am assured by many that it is already very extensive, but on the other hand I have already come across many instances of a lack of co-operation. These usually arise from the fact that a buyer often feels that he must use every possible means to knock down the price demanded by the seller. As a short-term policy this is sometimes useful, but from a long-term or national point of view such a policy can do nothing but harm. The Council of our Research Association has laid down as a strong point of policy that the research work of the Association is to be done in full co-operation with the suppliers serving our industry and the users of our products. Most of our work and organisations are already proceeding well in accordance with this policy and undoubtedly it will form an important part of our strength.

Labour

The other is co-operation with labour. At the moment the position is good, for the workmen of the country are becoming more and more research minded. Mr. Arthur Horner at a recent Institute of Fuel luncheon stated that miners formerly opposed research and technical developments which led to economy in the use of coal, because they might lead to less coal being required and miners put out of work. Now they had turned completely around and looked upon any man as their friend who made the material they had won so hardly with their hands worthy of their work. In the same way workers all over the country are beginning to demand that the tools that are given to them are worthy of the skill of their hands and brains. May they keep this attitude up when times are hard.

Given the drive and energy that we have seen this last six and a half years, we should undoubtedly achieve our objective before many years have passed. Unfortunately, other objectives and controversies are now tending to cloud the picture. We must all strive, however, to prevent being deterred from our main objective —British steel must be the best.

Reviews of Current Literature

Electron Optics and the Electron Microscope

THE past decade has seen the development of the electron microscope from a scientific curiosity into a tool of great practical worth. A huge field of direct visibility has been opened up, enabling us to see electron images of particles down to less than a millionth of an inch in size. More than 100 times smaller than previously visible in the optical microscope.

The literature on this subject has already reached large proportions much of it dealing with applications of the instrument. Many papers and several books have appeared mostly from Germany where practically all the pioneer work was done, though latterly many American papers have been published following the development and extensive use of the instrument in that country. The present book written by the group of workers mainly concerned with the development of the instrument in the U.S.A. contains a very complete account of its theory and practice.

The book is written in two distinct sections. The first section is concerned with the more practical aspects of the application of electron optics to the electron microscope, while the second section is almost exclusively devoted to the mathematical theory of electron optics and the microscope. It is perhaps unfortunate that the book was not published in two volumes for the separate parts are so obviously diverse and likely to appeal to different classes of readers.

In Part 1 entitled, " Practical Electron Optics and Electron Microscopy," after two introductory chapters describing the practical properties of the electron lenses and sources, and the diverse application of electron optics, is given a very complete explanation of the " Whys and Wherefores" of the electron microscope. This section makes an excellent introduction to the subject and should be of great interest to the reader who may be a user or a potential user of the instrument itself. Commencing with a simple explanation of the theory underlying the electron microscope performance the third chapter describes different types of instrument and compares their functions. In the following few chapters the more common magnetic type instrument is described in detail together with some factors affecting its performance. Constructional features described are mainly of

the R.C.A. model B instrument, though some details of other instruments are shown. A more critical comparison would have been useful here.

The final two chapters of the first section deal with the manipulations and use of the instrument. Only a limited space is devoted to specimen preparation, as is perhaps inevitable since the subject warrants a book in itself. The handling of the instrument is adequately described and the final chapter gives an interesting cross section of the application of the instrument in various fields of research. It is well illustrated with over sixty micrograms.

Part II entitled, "Theoretical Basis of Electron Optics and the Electron Microscope," is comprehensive and well written. It covers the mathematical derivation of the lens fields and electron trajectories as well as the lens aberration and defects. Several chapters are also devoted to the theory of image formation in the electron microscope including the effects causing contrast and limits to resolution.

Much of this section would be of more interest to the theoretical physicist than the user of the instrument, though the latter chapters on image formation are of practical importance to the user as a good understanding of the theory of contrast and resolution is important in the interpretation of results.

This 766-page book is pleasingly presented on a good art paper with clear print and is very adequately illustrated with diagrams and photographs which make up for rather sparse descriptions in places.

By V. K. Zworykin, G. A. Morton, E. G. Ramberg, J. Hillier, and A. W. Vance. Published by John Wiley & Son, Inc., New York, and Chapman & Hall, Ltd., London; Price 40/- net in Britain and $10 net in U.S.A.

Industrial Research

It is gradually being recognised that industrial progress is largely dependent upon research, which provides a fuller knowledge of materials and of power mediums available to mankind, and facilitates their development so that they can be applied economically for particular purposes. But, the results of research work come slowly to fruition and records of discoveries frequently lack the spectacular suddenness and surprise element, although the discovery of atomic energy can be regarded as an exception. Even when an important discovery has been made, however, persistent research is generally necessary to develop its economical applications to industry.

There can be no doubt that one of the most urgent lessons of the recent war is the importance of scientific research for industry in all its aspects. To regain and surpass our former standard of living demands the application of research to the problems of manufacture more actively than ever before. While attention must necessarily be given to pure research, from which important discoveries emanate, there should be the closest co-operation between research and industry so that discoveries and developments can be profitably applied in the minimum of time. Fortunately, as Professor Andrade states in the introduction of this book, the progressive commercial concerns of this country have taken vigorous measures to increase the scope and effectiveness of their laboratories and to invoke the aid of science in general.

This book, which is in the nature of an annual reference book on the subject, is divided into eleven sections, the first of which reviews work in various fields and each article in the section is presented by an authority. Such subjects as: science in industry; progress in the electrical industry; modern lighting; radar in war and peace; refrigeration and air conditioning; research in the gas industry; international collaboration in science; research in mechanical engineering; research in special steels; plastics; modern usage of wood; synthetic rubber production in U.S.A.; research and the textile fibres; industrial minerals; advances in paints and varnishes in U.S.A.; industrial standardisation; scientific instruments; the gas turbine; the Parliamentary and Scientific Committee; training for research; income tax and research; and several other aspects are discussed. The further sections deal with legislation and policy; official directorates; overseas research connected with the Dominions and Colonies, and with the U.S.A. and Sweden; official statements concerning various ministries, corporations and associations; unofficial statements concerning many other associations; officially appointed committees; directory of organisations interested; research laboratories; careers in industrial research; books, periodicals and films; and a who's who in industrial research. The book also includes a detailed index.

Professor Andrade is the advisory editor who aimed at presenting all points of view and to give factual and statistical information in as concise a form as possible, emphasising the importance of industrial science and research to those engaged in this field of work. The book comprises some 736 pages and should prove especially useful for reference purposes.

Advisory editor Professor E. N. da C. Andrade, F.R.S., D.Sc., Ph.D.; published by Todd Publishing Co. Ltd., London and New York; British distributors Geo. G. Harrap & Co. Ltd., 182, High Holborn, London, W.C. 1. Price 21/- net.

Tinplate

Although considerable research work has been devoted to improvements in the manufacture of tinplate over many years and world production in 1939 amounted to over four million tons, no book devoted entirely to the subject of tinplate has hitherto been published. This is rather surprising, especially in view of the wide distribution and familiarity of tinplate products, and this volume, therefore, should meet a need which has existed for many years. Much has, of course, been published on various aspects of tinplate manufacture, some information being included in works covering a wider subject, but mostly in technical periodicals, and in this book the authors have drawn upon the most authoritative of the literature on the subject with a view to giving a balanced account of aspects comprising history, manufacture, uses, properties, structure, testing methods, and corrosion resistance.

It is noteworthy that while the manufacturing processes are treated from a practical point of view the authors have not hesitated to give the research background from which the more recent developments have emerged, and references to original literature upon which they have drawn in preparing the text are given at the end of each chapter. The various chapters present such aspects as: the steel base of tinplate; hot rolling; continuous hot rolling; pickling; cold rolling annealing; tinning; the structure of tin coatings; the testing of tinplate; the corrosion of tinplate; electro-tinplate; and concluding sections include a statistical appendix, an author and subject indexes.

Since the introduction of tin coatings as a protection for steel sheet there has been a progressive tendency to reduce the tin coating, largely for economic reasons, but increased knowledge and improvement in technique of manufacture has permitted the use of thinner coatings without appreciable reduction in corrosion resistance. Strict measures of economy in the use of tin were necessary during the war with Japan and greater attention was given to the electrolytic process, thinner coatings than is possible by hot-tinning and they can be made thick or thin according to the service required of the material. With the modern continuous cold reduction process it has not been possible to use a continuous hot-tinning process excepting narrow widths, whereas the electrolytic process is adaptable for wide strip. It is probable therefore, that although the hot-tinning process will continue to be applied, the wider range of coatings possible by electrodeposition will rapidly bring about a greatly increased tonnage of tinplate processed by this method.

The subject is admirably presented in this book, which will be invaluable to both manufacturers and users of tinplate; in particular, much information is given which is of direct use to the box-making and canning industries. It is 9¾ in. × 7½ in. in size and has 292 pages with 151 illustrations.

By W. E. Hoare, B.Sc. and E. S. Hedges, D.Sc., Ph.D.; published by Edward Arnold & Co., 41–43, Maddox Street, London, W. 1; price 40/- net.

Principles and Practice of Heat-Treatment

Heat-treatment has an important part to play in all kinds of engineering and, with the more scientific approach to the subject of recent years, its influence on the finished product is becoming increasingly appreciated. In the broadest sense, the term heat-treatment embraces all processes which involve heat and by which the physical or mechanical properties of metals and alloys are affected; it can therefore be said to be associated with practically all processes from the ores to the finished metal component. So important is this subject of heat-treatment that its study has been said to be of more practical importance than the search for new alloys; further, the useful effect of the addition of new elements is generally entirely dependent on a heat-treatment, without which the result would be of little interest.

This book is concerned with the principles and practice of heat-treatment and deals with some of the main practical aspects of the subject. It is a second edition and, while the original arrangement in presenting the subject has been preserved, an additional chapter on inspection of components has been included, together with other minor additions. It carries 108 pages and 39 illustrations, and, although enclosed in paper covers, it is remarkably cheap in these days.

By J. Winning; published by Emmott & Co. Ltd., 31, King Street West, Manchester, and 21, Bedford Street, Strand, London, W.C. 2. Price 3/6 net.

Heat-Treatment of Metals and Alloys

(*Continued from page* 28).

natural ageing (solution heat-treated), and the other after a double heat-treatment in that solution heat-treatment is followed by artificial ageing (fully heat-treated). A summary of these wrought alloys is given in Table II.

Because of the very limited solubility of many of the common metals in magnesium, the development of hardenable alloys has been slow. In current British practice heat-treatment is seldom applied to wrought alloys, but the properties of certain casting alloys can be improved by heat-treatment. In Table III are shown the effects of heat-treatment on the mechanical properties of the Electron alloys A8 and AZ 91. In order to obtain a uniform solution treatment in those alloys it is necessary to have a fine uniform grain size in the cast alloy. Solution treatment is said to proceed much more rapidly if the temperature is slightly elevated, and direct precipitation treatment has also been suggested. Magnesium alloys containing over 8·5% of aluminium have to be annealed and stress relieved after heat-treatment.

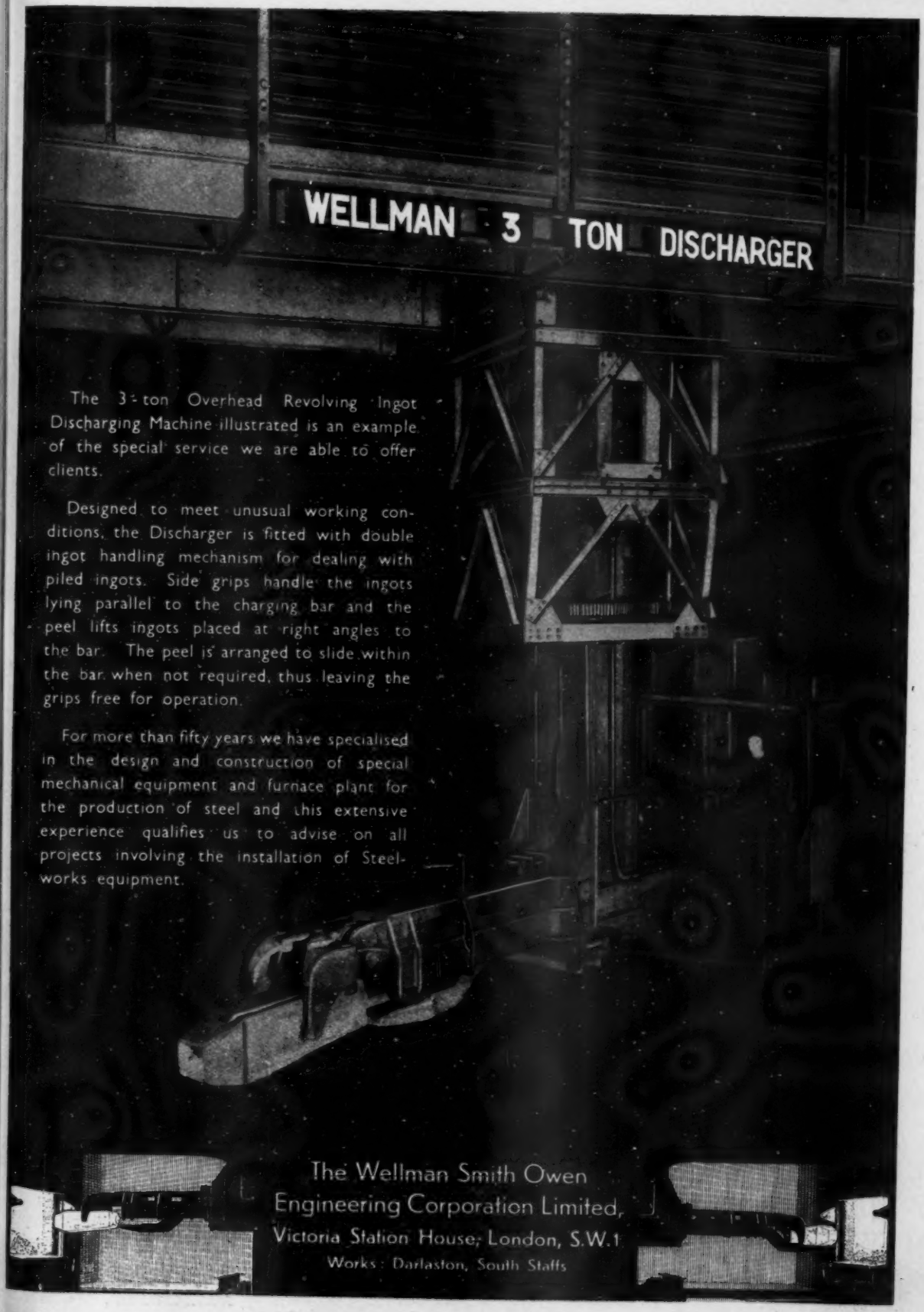
The precipitation hardening beryllium alloys of copper and also of nickel have found many applications during recent years so far as has been consistent with beryllium supplies. The copper-beryllium, 2·5% beryllium; the copper-cobalt-beryllium, 0·5–2·6% cobalt, 2–2·6% beryllium; and the nickel-beryllium, 1·9–2·5% beryllium, 0·5–1·0% manganese, alloys give excellent mechanical and physical properties after suitable heat-treatment. The fatigue resistance of these alloys is high and renders them particularly suitable for springs for use at high temperatures.

Certain alloys of nickel are susceptible to heat-treatment, and can be rendered either soft and ductile or strong, hard, and of high elastic limit. Heat-treatment generally consists of softening by rapid cooling from 800°–850° C. and hardening by reheating to temperatures in the range 400°–650° C. Heat-treatable nickel alloys include high nickel-copper alloys (Monel Metal), nickel-brasses, nickel-bronzes and nickel silvers. In all such alloys composition has to be adjusted to render them suitable for treatment. As an industrial heat-treatable alloy, K Monel Metal, which contains besides the usual constituents of Monel Metal, 2·5–4·0% aluminium, after water quenching, hard rolling or hard drawing and reheating, gives a tensile strength of over 70 tons/sq. in., with an elastic limit of over 50 tons/sq. in., an elongation of 20% and a Brinell hardness of 300.

TABLE III.—THE EFFECT OF HEAT-TREATMENT ON THE MECHANICAL PROPERTIES OF THE ELECTRON ALLOYS A 8 AND AZ 91 (FOX*).

D.T.D. Specification	Electron Alloy	Nominal Composition (About 0·3% Mn is also present in each case).	Condition.	0·1 Proof Stress Tons/Sq. In.	Ultimate Stress Tons/Sq. In.	Elongation % on 2 In.
59A	A8	Mg + 8% Al + 0·4% Zn	As cast.	5·3	10·5	3·0
289	A8	Mg + 8% Al + 0·4% Zn.	Solution treated.	5·1	17·0	12·5
136A	AZ.91	Mg + 9·5% Al + 0·4% Zn.	As cast.	6·0	9·6	1·5
281	AZ.91	Mg + 9·5% Al + 0·4% Zn.	Solution treated	6·0	17·0	9·0
285	AZ.91	Mg + 9·5% Al + 0·4% Zn.	Solution treated and precipitated	7·5	17·0	1·5

* METALLURGIA, 1945, Vol. 32, No. 187, pp. 20—23.



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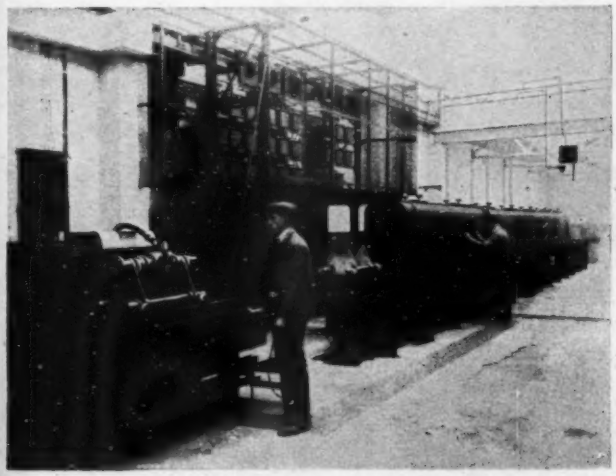

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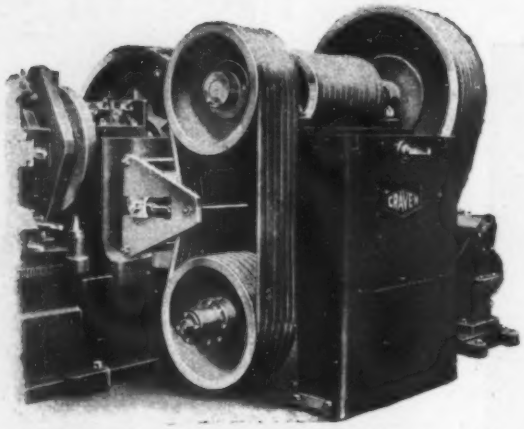

View of Roll Revolving Headstock from the front showing multiple vee-belt drive

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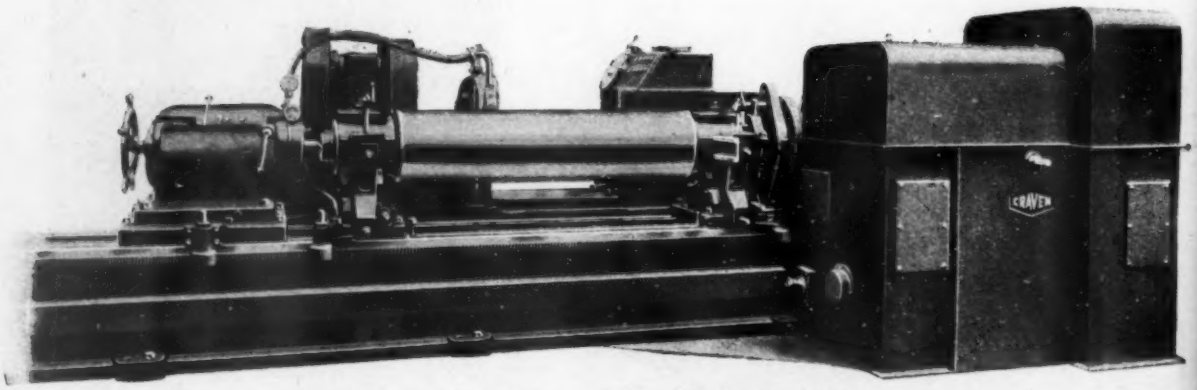
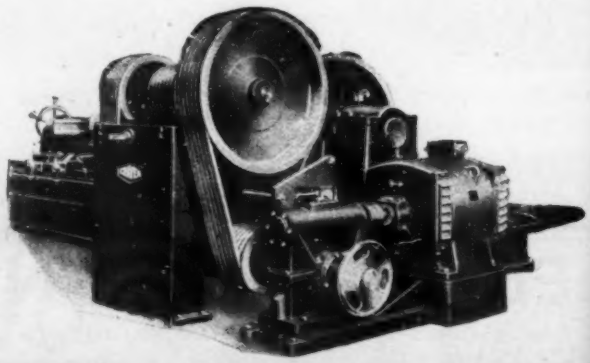


The illustration shows a machine of the traversing-grinding-head type for rolls 6 in. to 30 in. diameter

View of Roll Revolving Headstock with covers removed showing motor, worm reduction unit and multiple vee-belt drive



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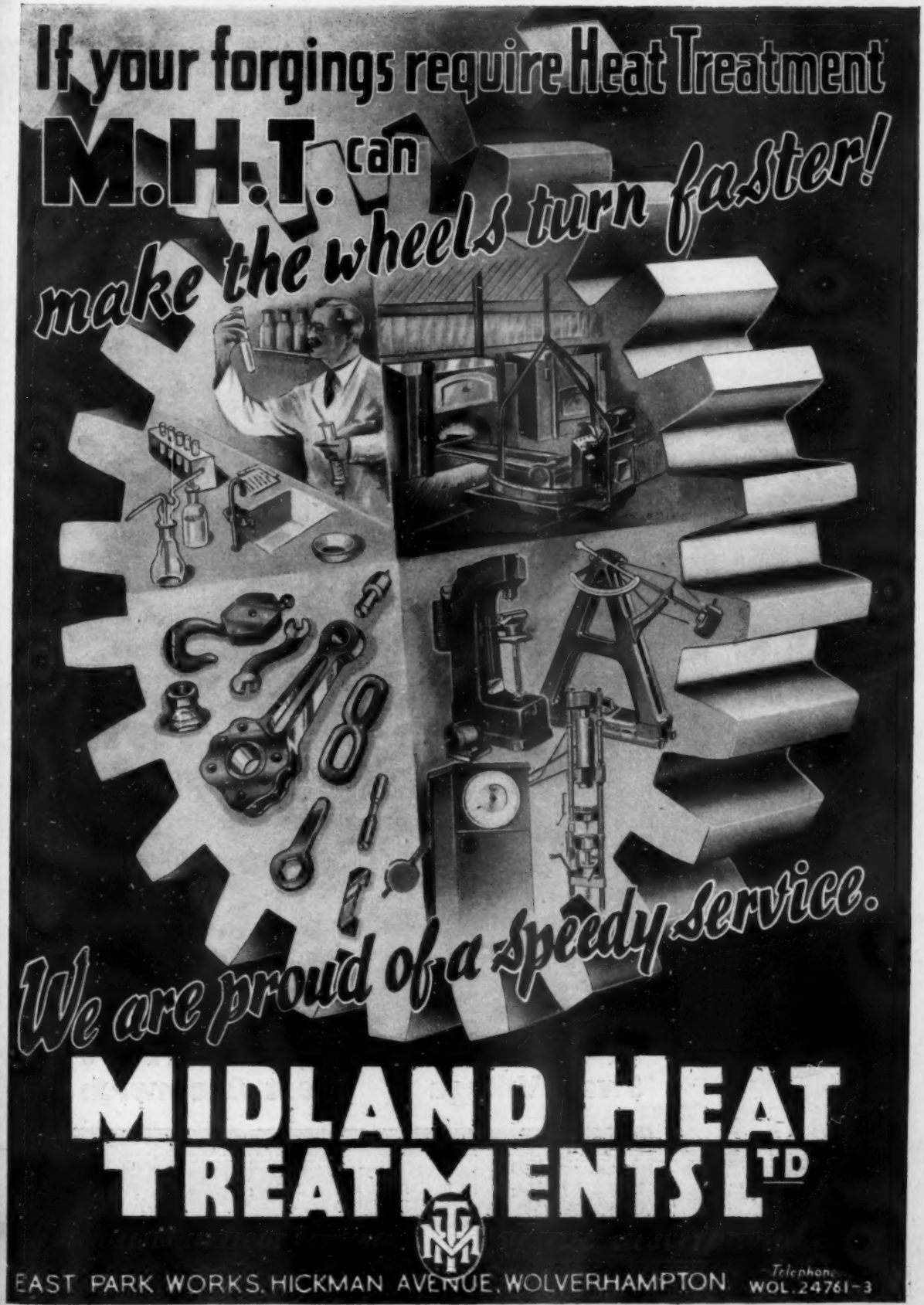
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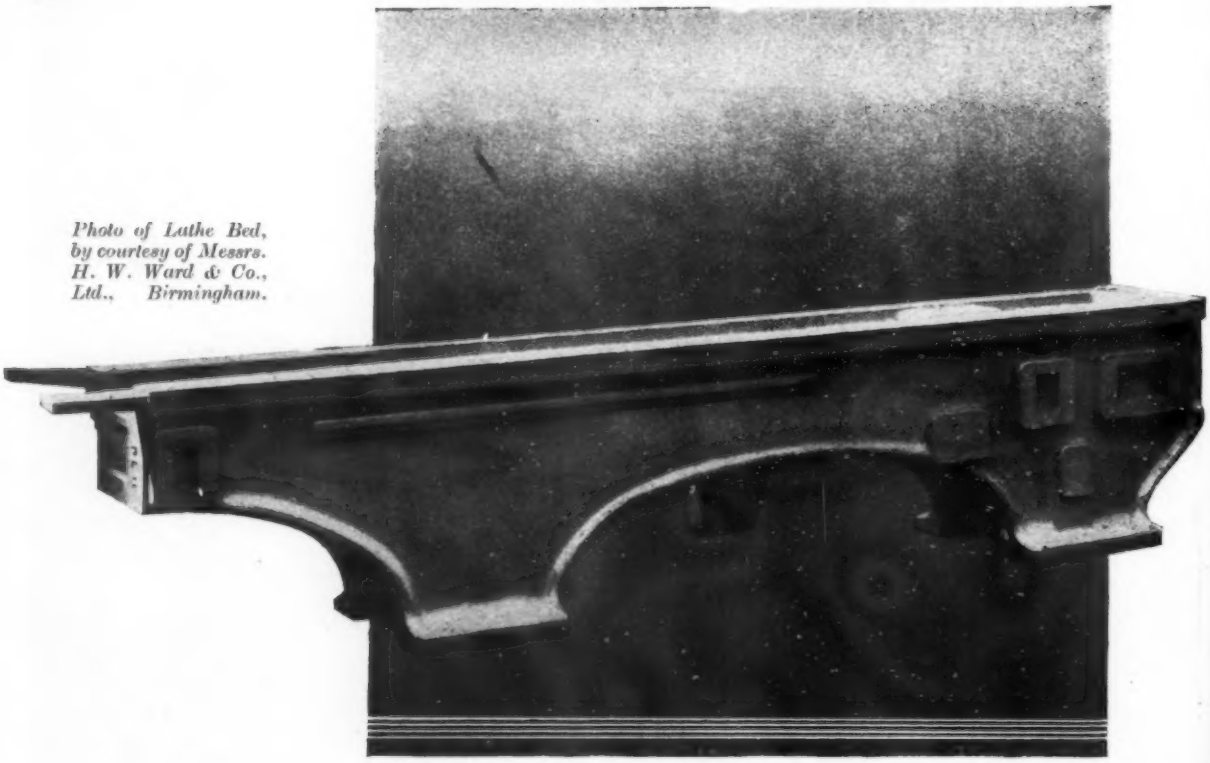

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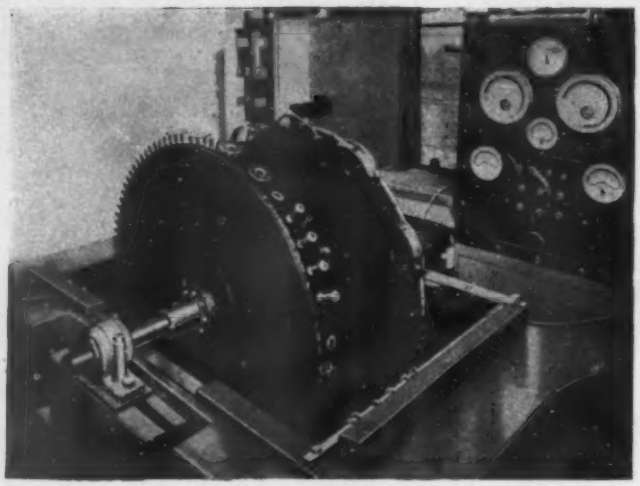

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Heat-Treatment of Metals and Alloys

By J. W. Donaldson, D.Sc.

The war years have caused considerable development in heat-treatment technique, partly as a result of limitations in the use of alloying elements, which involved greater care in the treatment of alloy steels, for instance, to provide the required properties, and partly as a result of progress in knowledge of metals and alloys. But ferrous alloys are not the only alloys improved by quenching, hardening and age-hardening; many non-ferrous alloys respond to heat-treatment and their field of usefulness is continually increasing as a result. This article briefly reviews the more recent developments and improvements in the industrial heat-treatment of both ferrous and non-ferrous metals and alloys.

THE demands of war production have necessitated improvements in technique in many metallurgical operations and included among these have been developments and improvements in the industrial heat-treatment of both ferrous and non-ferrous metals and alloys. Such improvements have not only resulted from war-time conditions, but have also been required to meet the advances which have taken place resulting from improvement in the quality of steel and the development of new heat-treatable non-ferrous alloys. The necessity of controlling grain size, and the surface condition of materials which have been heat-treated have also given rise to many new and interesting problems in heat-treatment.

To bring about improvements in heat-treating methods and techniques to meet such conditions, it has been necessary to deal with such variables as furnace temperatures, furnace atmospheres, heating times, cooling rates and quenching methods. Such changes have not only been carried out by improvements in gas-fired and electric heating-treating furnaces; by an extended use of salt baths for heating; by the use of better and more rigidly controlled pyrometers of all types, thermo-electric including base metal thermo-couples and radiation and optical pyrometers; by the development and applications of controlled atmospheres and by the use of proper quenching medium and equipment; but also by a better understanding of the principles of heat-treatment as applied to various metals and alloys. The determination of such principles has led to a considerable number of investigations and researches, and during recent years much data has been made available regarding the hardenability of metals and alloys and particularly of steel.

Hardenability of Steel

The metallurgy of steel heat-treatment has formed the subject of many investigations over a long period, and, during comparatively recent years, the results obtained from such investigations have changed the industrial heat-treatment of steel from an art into a science. To select the proper steel for a particular part the user of the steel, engineer, designer, or metallurgist, has to compare the hardening power or hardenability of the steels available with the strength requirements in the part. Hardenability which is the measure of the depth to which a steel will harden on quenching is not concerned with the maximum hardness obtainable on quenching, which depends on the carbon, although such hardness is also of the greatest importance in the heat-treatment of steel. The hardness of a steel depends on its composition and method of manufacture, on the section of the steel being treated, and on the quenching medium and the method of quenching. Ordinary carbon steels, on account of their low carbon content, have a low hardenability and are therefore not susceptible to deep hardening.

Many methods, comparative and quantitative, are available for determining the hardenability of steel, but possibly the simplest and most accurate is that based on the fact that the as-quenched hardness of any steel is determined by the speed of cooling during quenching. This method involves hardening a bar of steel so as to obtain a wide range of hardness from the surface to the centre of the bar after hardening. If at the same time an end-quench test, as devised by Jominy in the United States, is made, using a bar of the same heat of the steel from the same hardening temperature, the equivalent cooling rate value for any as-quenched hardness value may be determined from the end-quenched harden-ability. By determining, therefore, the cooling rate at any point in a given part, and by means of hardenability curves of the various types of steel available, it is possible to choose a steel of the specified hardness for the required part.

The practical application of the theoretical conception of isothermal transformations in steel has also been an outstanding development in the heat-treatment of steel. The effect of time on the isothermal transformation, as given by the S-curve, and the application of such a curve for a given steel is of great importance in determining the correct temperature of the quenching bath and of the holding time. The process of austempering which has become largely used for certain steels, particularly in the United States, for ordnance and other war materials, uses the S-curves and consists of quenching a plain carbon or alloy steel from a temperature above its critical point into a bath at a temperature between 175° and 315° C. and holding it there until it is completely transformed. In martempering, which is based on a knowledge of the temperatures at which the beginning and end of the transformation to martensite in a particular steel occurs, a method of quenching steel has, comparatively recently, been successfully developed with the object of preventing distortion and residual stresses. In this process a quenching medium, usually a bath of molten salts, is selected so that there is a minimum temperature difference between outside and centre of the part treated, when the outside reaches the temperature at which martensite begins to form, and the part is held sufficiently long in the bath for its temperature to become uniform, after which it is cooled in air.

Heat-treatment of Steel

The industrial heat-treatment of steel at the present time either demands the treatment of a large section of steel in which a high hardness is required or a controlled depth of hardness, or the obtaining of a high hardness and strength from shallow hardening steels of low alloy content. The properties obtained by both treatments have also to be obtained without undue distortion or cracking and without damage to surface layers. With regard to the first type of treatment, deep hardening in large sections is only obtained in steel of high alloy content, although heating methods and quenching rates have also an important effect. Improved quenching methods have been found in the application of submerged jet quenching, accompanied by rotation or movement of the part, and by the use of quenching oils with cooling characteristics nearer to those of water than to those obtained in the conventional quenching oil. The time quenching of such steels is also used to control the depth of hardness. In highly alloyed steels of medium and higher carbon contents the depth of hardening can be controlled by continuous quenching which also eliminates cracks, and for suitable sizes and composition good results in such steels are said to result from austempering and martempering.

During recent years, considerable attention has been given to the heat-treatment of the lower alloy steels of weaker hardening characteristics, particularly as to depth hardness, surface hardness and the hardening of larger sections. This has been brought about by the necessity for conserving alloy elements for economic and strategic reasons, and for obtaining the best properties in the substitute steels consistent with the duties they had to perform. In the Schedule of steels dealing with the shortage of alloying elements, designated the En Steels, 43 alloy steels were specified in the form of bars, billets, light forgings and stamping up to a ruling section of 6 in. In addition, two new specifications were added later to assist in taking advantage of the alloy content of steel scrap, one for heat-treated low alloy steel bars (En 100) and the other for a low nickel-chromium-molybdenum steel (En 110). Specifications were also issued for an additional three alloy case-hardening steels. Of the 48 dealt with, 11 were low alloy steels, 11 were ordinary alloy steels, 10 were alloy case-hardening steel, 2 were nitriding steels, 4 were alloy steels for springs, 7 were alloy steels for valves and 3 were for stainless and for austenitic heat-resisting steels.

In Table I are given the compositions of the low alloy steels, together with their properties after heat-treatment. The carbon chromium steel, En 11, after oil hardening from a temperature of 800°–850° C., followed by tempering at a suitable temperature not less than 450° C., only gives the properties specified in sizes up to 2½ in. ruling section. The manganese-nickel-molybdenum steel gives the values specified in all sections up to 6 in. after hardening in oil from 850°–890° C. and tempering at a suitable temperature between 550° and 670° C. Properties specified are obtainable in all sizes up to 4 in. ruling section in the carbon-manganese steel, En 14, and up to 6 in. ruling in the higher carbon manganese steel, En 15, by oil hardening from 840°–880° C. and tempering between 550° and 660° C. Satisfactory properties are obtained with both manganese-molybdenum steels En 16 and 17, in sections up to 6 in. after oil or water hardening from 830°–860° C., followed by tempering at not less than 530° C. The water hardening treatment is suitable for steels with a carbon content of 0·20–0·35% and the oil hardening treatment for steels with a carbon content of 0·3–0·4%.

Ultimate tensile strengths ranging from 45–55 tons/sq. in. are obtainable up to 4 in. section in 1% chromium steel, En 18, by oil or water quenching from 850°–870° C., followed by tempering between 550° and 700° C. The first of the two chromium-molybdenum steels, En 19, gives the properties specified in Table 1 in all sections up to 6 in. after heat-treatment, consisting of oil quenching from 850°–870° C. and tempering between 550° and 700° C., while in the second steel, En 20, satisfactory mechanical properties are only obtained up to 2½ in. ruling section after water hardening steel with a carbon content of 0·22–0·35% and chromium not above 1% and oil hardening steel with a carbon content of 0·35–0·50%. Suitable tempering temperatures for both steels are between 600° and 700° C. The alloy steels, En 100 and En 101, give the mechanical properties specified in all ruling sections up to 6 in. after heat-treatments consisting of oil or water quenching from 830°–860° C., followed by tempering at not less than 530° and 660° C. respectively.

The other alloy steels in the En series are oil or hardened steels and the mechanical properties specified are usually obtained in all sizes up to ruling sections of 6 in. In some of the steels such as the nickel-chromium-molybdenum steel, En 29, there is a marked absence of mass effect, unless the ruling section is relatively large, and in other steels such as the 4½% nickel-chromium-steel, En 30, specified properties up to 2½ in. can be obtained by air hardening and such treatment is preferred. The alloy case-hardening steels of the En series may be either oil or water quenched according to the core strength desired. Nickel-chromium steels of this type are much less susceptible to mass effect when heat-treated than nickel case-hardening steel and are therefore more suitable for large sections.

TABLE I.—LOW ALLOY STEELS.—En SERIES.

En No.	Composition					Yield Point Min. Tons/ Sq. In.	Ultimate Strength Min. Tons/ Sq. In.	Elongation Min. %	Brinell Hardness
	C	Mn	Ni	Cr	Mo				
11	0·5–0·7	0·5–0·8	—	0·5–0·8	—	28–45	55–65	12–15	241–352
13	0·15–0·25	1·4–1·8	0·4–0·7	—	0·15–0·35	30	40	22	163–241
14	0·2–0·3	1·3–1·8	0·4	—	—	30	40–45	20	156–269
15	0·3–0·4	1·3–1·7	—	—	—	28–38	40–50	22	163–293
16	0·25–0·4	1·3–1·8	—	—	0·2–0·35	34–52	45–65	16–22	192–352
17	0·3–0·4	1·3–1·8	—	—	0·35–0·55	34–52	45–65	16–22	192–352
18	0·35–0·45	0·6–1·2	—	0·8–1·2	—	32–44	45–55	18–22	192–311
19	0·35–0·45	0·5–0·8	—	0·9–1·5	0·2–0·4	34–58	45–70	15–22	192–375
20	0·22–0·5	0·4–0·8	0·3	0·5–1·5	0·4–1·0	40–55	55–65	16–17	241–352
100	0·35–0·45	1·2–1·5	0·5–1·0	0·3–0·6	0·15–0·25	34–52	45–65	16–22	192–352
110	0·35–0·45	0·4–0·8	1·2–1·6	0·9–1·4	0·1–0·2	34–58	45–70	15–22	192–375

Controlled Atmospheres for Steel Treatment

Steels with weak hardness characteristics, particularly as to depth hardness and surface hardness, demand minimum amounts of surface decarburisation, so that the thickness of the already shallow zones shall not be reduced still further. Machining must be carried out to, or to almost the finished size, before heat-treatment, and controlled atmospheres are therefore being increasingly used for heating before quenching and also where annealing is carried out in parts where surfaces have not to be machined. The use of a separately produced atmosphere makes it possible to harden intricate parts without decarburisation or oxidation of surfaces and by the elimination of scale with its insulating effect on quenching gives better hardness. Controlled atmospheres, besides rendering unnecessary the need for machining or grinding, also eliminates cleaning and sand-blasting.

In the application of controlled atmospheres to the bright hardening and bright annealing of steel, the atmosphere is usually produced by the partial combustion of fuel gases under controlled conditions, and if decarburisation is to be prevented, such an atmosphere must be very low in CO and H_2O. Improved equipment has been developed during recent years for the production of such atmospheres and also devices for measuring the atmosphere required for a given steel at a given temperature in order to obtain equilibrium conditions on the surface of the steel.

Salt Bath, Induction and Flame Hardening

The protection of surfaces from decarburisation and scale can also be carried out by the use of salt baths, a method of heating which has great advantages in speed and accuracy over the usual methods, and which has made progress during recent years. Salt bath heating, besides protecting the surface during heating, can also be made to control the depth and location of hardened zones, a feature which is sometimes desired in steel parts. The progress made in this method of heating in recent years has resulted from production methods and has been accompanied by considerable developments in equipment.

Induction heating, which is rapid, clean and particularly suited for surface hardening, has also made progress during the war period in the applications to which such heating has been put, resulting particularly from developments in induction heating equipment. The electronic tube has been adapted for the heating of small parts and for the hardening of very thin layers up to 0·050 in.

Flame hardening, another method which is also rapid, clean and specially suited for surface hardening without scale, is in use for hardening large parts which would be liable to distortion, if hardened by other methods of treatment, and also for hardening irregular shapes and parts requiring local hardening. Recent developments in flame hardening have been made in technique, where specialised methods of flame direction and quenching have been adopted, and in heating by such economical methods as the radiant tube burner.

Heat-treatment of Cast Iron

For some years heat-treatment has been applied to certain types of cast iron with a response similar to that obtained with carbon steels. The result of such heat-treatment is to improve the strength, toughness and hardness. The types of cast iron most susceptible to treatment are the alloy cast irons containing 2% nickel 1·5% nickel, 0·5% chromium; 0·5% molybdenum; 0·2% nickel, 0·4–0·5% chromium, 1·0–1·3% copper, respectively, and with carbon contents ranging from 3–3·5%. Treatment is usually carried out by heating to 850°–875° C. and quenching in oil or water according to the hardness desired. Hardness after quenching is not unduly influenced by tempering at temperatures up to 200° C., so that when full hardness is desired, tempering to remove hardening stress is usually carried out at 150°–200° C. Maximum strength and toughness are obtained by tempering in the range 380°–430° C., when strength values of over 30 tons/sq. in. are obtained. Where hardness in combination with strength and toughness is required, tempering at 250°–375° C. is suitable, and for good wearing properties tempering over the range 550°–600° C. Heat-treated iron castings have been increasingly used during the last five years for many parts and have replaced steel castings in many cases.

Other heat-treatment processes applied successfully to cast iron are the nitriding of special alloy cast irons to develop a case of 0·01–0·015 in. deep; flame hardening to obtain hardness ranges from 450–600 Brinell for such parts as gears, cams, sleeves, dies and liners, and induction hardening for hardening the internal surfaces of cast iron cylinder liners to a depth of 0·07 in.

Heat-treatment of Non-ferrous Alloys

Heat-treating processes for non-ferrous metals and alloys are not so diverse as those for steel and other ferrous alloys. In general processes for non-ferrous alloys may be divided into two types, bright annealing and age-hardening. Bright annealing with few exceptions to copper and nickel and their respective alloys, and age-hardening to certain aluminium and magnesium light alloys and to such copper alloys as copper-beryllium and copper-nickel alloys. Advances which have taken place during recent years have had to deal with the production of new heat-treatable alloys, changes in the processing of the older heat-treatable alloys, and an extended use of salt baths for heating and of protective atmospheres for annealing.

The heating of non-ferrous alloys in molten salts has progressed considerably, and such progress has been accompanied by developments in salt bath equipment whereby it has been possible to heat large parts and sections. Salt baths have been used to a large extent as the heating medium for the solution treatment of aluminium alloys. Where parts treated are small, precautions have to be taken to prevent corrosion, when in contact with molten salts, and alloy containers or cylinders which act as small furnaces and are heated by the molten salts are used. Good results are said to result, however, from the individual treatment of large sheet section of aluminium alloys, both as regards speed of operation and control of distortion.

Bright Annealing

For bright annealing non-ferrous metals and alloys separately prepared controlled atmospheres are used similar to those used for steel, except in certain cases where the furnace atmosphere may be produced by proper furnace control from the products of combustion of the heating gas. The greater part of copper used at the present time is treated in a controlled atmosphere derived from ammonia or hydrocarbons and discharged

TABLE II.—HEAT-TREATED WROUGHT ALUMINIUM ALLOYS. BS/STA 7 SERVICES SCHEDULE, 1945.

No.	Description	Composition									Condition	0·1 Proof Stress Min. Tons/ Sq. In.	Ultimate Stress Min. Tons/ Sq. In.	Elongation Min. % on 2 In.
		Al	Cu	Mo	Fe	Si	Mn	Ni	Zn	Other Element				
AW 9	(*a*) Bars and Sections ..	Rem	—	0·4–0·8	0·6	0·3–0·6	—	—	—	—	Solution heat-treated ..	5	9	18
	(*b*) Bars and Sections ..										Fully heat-treated ..	10	12	16
AW 10	(*a*) Bars, Sections and Forgings	Rem	—	0·5–1·25	0·6	0·75–1·3	1·0	—	—	—	Solution heat-treated ..	7	12	18
	(*b*) Bars, Sections and Forgings										Fully heat-treated ..	15	18	10
AW 11	(*a*) Bars and Sections ..	Rem	2·0	0·5–1·25	0·75	0·75–1·25	1·0	0·25	0·10	Sn 0·04 Pb 0·05	Solution heat-treated ..	10	17	15
	(*b*) Bars and Sections ..										Fully heat-treated ..	17–20	23–25	6–8
AW 12	Forgings	Rem	1·8–2·5	0·65–1·2	0·6–1·2	0·55–1·25	—	0·6–1·4	0·10	Ti 0·3 Sn 0·04 Pb 0·05	Fully heat-treated ..	21	27	10
AW 13	Wire and Rivets	Rem	1·5–3·0	0·2–0·5	0·7	0·7	0·5	0·7	0·10	Ti 0·3 Sn 0·04 Pb 0·05	Solution heat-treated ..	—	17	—
AW 14	Wire and Rivets	Rem	3·5–4·5	0·4–0·9	0·7	0·7	0·4–0·7	0·25	0·10	Ti 0·3 Sn 0·04 Pb 0·05	Solution heat-treated ..	—	25	—
AW 15	(*a*) Bars, Sections and Forgings	Rem	3·5–4·8	1·0	1·0	1·5	1·2	0·25	0·10	Ti 0·3 Sn 0·04 Pb 0·05	Solution heat-treated ..	10·5–15	20–25	8–15
	(*b*) Bars, Sections and Forgings										Fully heat-treated	24–28	28–32	8
AW 16	(*a*) Bars and Sections ..	Rem	3·0	4·0	0·6	1·9	1·0	—	4–8	Ti 0·3 Cr 0·1	Fully heat-treated ..	30–33	35–38	5
AW 17	(*a*) Forging & Stampings	Rem	3·5–4·5	1·2–1·7	0·6 Fe and Si 1·0	0·6	—	1·8–2·3	0·1	Ti 0·3 Sn 0·04 Pb 0·05	Fully heat-treated ..	14	24	15
AW 18	Forging and Stampings suitable for Cylinders and Piston Heads ..	Rem	1·5–3·0	1·2–1·8	1·0–1·5	1·3	—	0·5–1·5	0·1	Ti 0·3 Sn 0·04 Pb 0·05	Fully heat-treated ..	—	25	6

from the furnace in a dry condition. In such an atmosphere hydrogen should not exceed 5%, otherwise there is danger from hydrogen embrittlement in oxygen-containing copper. Sulphur compounds, particularly sulphuretted hydrogen (H_2S) should also be absent, and special methods have been established for moving such compounds. The bright annealing of brass and bronze is usually carried out in an atmosphere prepared from cracked or dry burnt ammonia free from oxygen, sulphur, H_2O, CO_2 and CO, and care has to be taken to prevent volatilisation of zinc. Using such an atmosphere up to about 400° C., under a reduced pressure in a specially designed furnace, has been found to give good results. Nickel and nickel alloys usually require conditions for bright annealing intermediate between those for steel and those for copper alloys. High nickel-chromium alloys are treated similar to high chromium steels, and nickel-copper-zinc alloys (nickel silvers) with a high zinc content similar to brass. In both cases H_2S and other sulphur compounds must be absent. Besides being used in annealing, controlled atmospheres are also used in the automatic brazing and soldering of non-ferrous alloys.

Age-hardening

The heat-treatable non-ferrous alloys are alloys susceptible to solution treatment or age-hardening, and consist principally of certain light alloys of aluminium, certain light alloys of magnesium, copper-beryllium alloys and certain nickel bronzes, together with certain alloys of the rarer metals not used industrially. In all age-hardening alloys, the heat-treating procedure must be adapted to a carefully controlled alloy composition and particular attention has to be given to the quenching medium, the sensitivity of the alloy at the moment of quenching, the production of internal stresses and the necessity for further treatment after quenching.

As regards aluminium alloys, those which are heat-treatable, either cast or wrought, when cooled fairly rapidly from a temperature of 500° C., are susceptible to an increase in strength and hardness. The magnitude of this effect (ageing or precipitation hardening) depends on the type of alloy; and in certain cases in order to increase the degree of hardness obtained, recourse is made to heating for a number of hours at a temperature of 165° C. (artificial ageing treatment). Most aluminium castings are used in the as-cast condition, but where high strength is required this may be obtained in certain alloys by heat-treatment. Alloys such as the copper-magnesium-silicon-nickel-iron, sand and gravity die casting alloy, are given a low temperature artificial ageing treatment, others such as the 10% magnesium, sand and gravity die casting alloy are given a high temperature solution heat-treatment, while others such as the 3·5–5·5% copper, 1·8–2·3% nickel, and 1·2–1·7% magnesium, die casting alloy are given a combination of the two forms of treatment. The wrought aluminium alloys which require treatment at elevated temperature have been outlined in the Schedule of Service Non-Ferrous Metals and Alloys, BS/STA 7, issued in 1945 by the British Standards Institute. These alloys are divided into two sub-groups, one of which contains alloys which attain their full strength after solution heat-treatment and spontaneous or

(*Continued on page* 24).

Some Recent Heat-Treatment Furnace Installations

Equipment Developed for Ferrous and Non-Ferrous Metals

The unprecedented demand during the war for ferrous and non-ferrous components has necessitated considerable development in heat-treatment equipment. The object in view, mainly, has been to simplify the operations, to overcome the difficulty of using unskilled labour, but developments in technique have also called for improvements. It is not possible in a review of plant of this kind to describe the many developments in heat-treatment furnace design during the war but several examples are given, some of which have been on the secret list, in order to indicate various directions in which improvements have been made.

THE trend of furnace design in recent years has been mainly to simplify the operation, to overcome the difficulty of using unskilled labour. All modern furnaces are equipped with automatic temperature control, and, where the process makes it necessary, automatic heating cycle regulators. This makes possible results to meet the exacting demands of present day metallurgy without requiring a large staff of skilled men. In effect, furnaces, particularly the electrically heated type, are becoming precision instruments. To suit the requirements of modern production methods, mechanical handling equipment is being increasingly employed. This equipment, which has full electrical and mechanical interlocking gear, has made possible the use of female labour and other unskilled workers, previously considered unsuitable for heat-treatment operations.

The stringent demands on ferrous and non-ferrous alloy components have imposed restrictions on the liberties that can be taken in obtaining the desired properties, especially in view of the need to reduce alloy additions of critical elements to a minimum. In many instances, especially for aircraft engines, it was necessary to subject alloy steels to preliminary heat-treatment to improve their quality. Considerable attention has been given to clean annealing, and great improvements have been made in the use of artificial atmospheres. It is now possible to bright anneal or heat-treat almost all metals. Apart from the utilisation of an atmosphere to protect the charge from oxidation or decarburisation, specified mixtures are used to give certain properties to the metal. Notable among these processes is nitriding, where special steels are heated in an ammonia atmosphere; by the absorption of nitrogen obtained by the dissociation of this gas, the surface of the steel becomes hard, without need for further heat-treatment. The atmospheres most commonly used to-day are those derived from :—

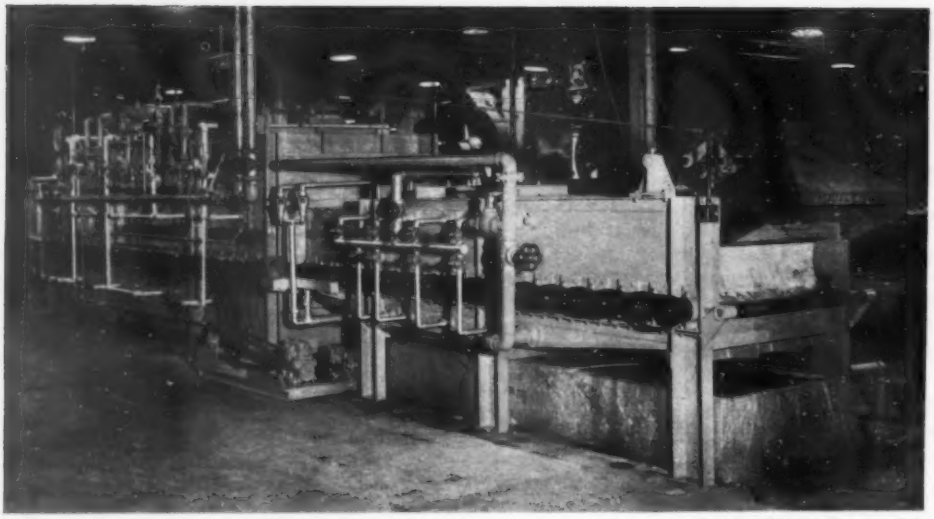
1. The incomplete combustion of coal-gas.
2. Dissociated or cracked anhydrous ammonia.
3. Cracked and burnt anhydrous ammonia.

Other gases and fuels are being utilised and there are still great possibilities in this field of research.

While "box carburising" continues to predominate as a method by which a hard, wear-resisting surface can be given to many steels, attention has been given to liquid carburising, cyaniding and gas carburising; a new controlled atmosphere plant for carrying out the process was described in the last issue of this journal

Courtesy of Wellman Smith Owen Eng. Corp., Ltd.

Fig. 1.—Heat-treatment furnace for the step treatment of alloy steel ingots.



Courtesy of British Furnaces, Ltd.

Fig. 2.—Roller hearth furnace for clean annealing non-ferrous material. It is 37 ft. long and is designed for operating at temperatures up to 620° C.

and further reference is made to the process in the present review. For all heat-treatment processes, however, there have been considerable advances, and while this applies to what are generally regarded as general purpose furnaces, it is specially applicable to special purpose furnaces for which the necessities of war caused an increased demand.

Alloy Steel Ingot Heat-treatment Furnace

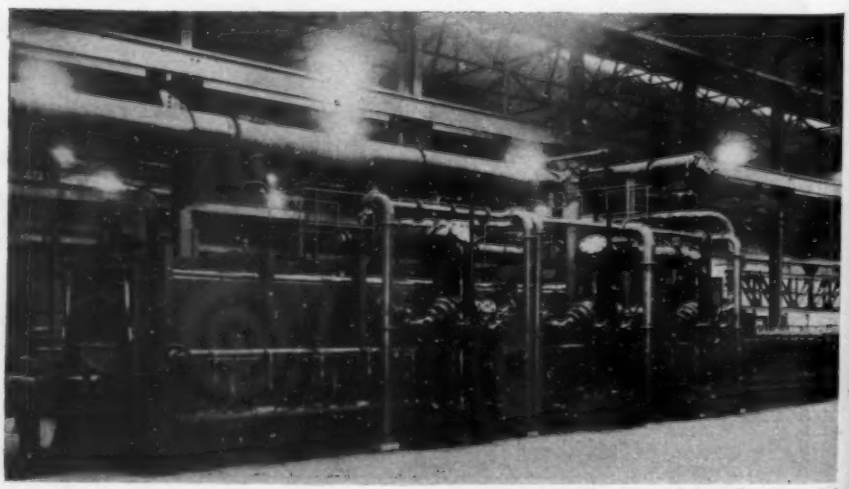
In order to improve the quality of an alloy steel for special purposes large ingots were subjected to a heat-treatment process extending over a period of 72 hours at various temperatures and rates of soaking, cooling, re-heating, further soaking and final cooling in air. The whole process being known as step treatment. The special steel ingots to be treated weighed from 17½ cwts. up to 2-tons each and varied in size from 11–12 in. square up to 16–20 in. square.

A heat-treatment furnace for dealing with these ingots was designed by Wellman Smith Owen Engineering Corporation and a battery of 12, shown in Fig. 1, was installed at one plant. Owing to the rapidity with which this plant had to be designed and constructed, it was decided to use that type of fuel which needed the least amount of new equipment for its use and distribution, provided that the close limits of the heat-treatment required could be satisfactorily attained. This question was explored and a decision was made in favour of solid fuel fired by means of under-feed mechanical stokers automatically controlled by means of a programme regulator.

The furnace is a bogie type, the bogie being designed to carry a batch of ingots weighing a maximum of 80 tons. The effective size of the bogie hearth is 21 ft. 6 in. long × 12 ft. 6 in. wide, and the maximum height of the heating chamber above bogie hearth level 11 ft. 3 in. To carry the heavy weight of stock and bogie and to facilitate its easy removal in and out of the furnace, the bogie is mounted upon two sets of articulated cast steel balls running between top and bottom hollowed track rails. For simplicity the hauling of the bogie in and out of the furnace is carried out by means of the shop crane, fixed pulleys being arranged below the bogie and at the end of its travel for this purpose. The working clearance between the furnace side and end walls and the bogie is sealed by means of a sand seal. The charging door is also sealed at the top and on the bogie hearth and provided with clamps at the sides.

The heating of the furnace is effected by two No. 35 Mirrlees "Combustioneer" mechanical stokers, each of which is applied to a separate combustion chamber constructed at the rear of the furnace and arranged to fire into the heating chamber over an air cooled bridge wall. The furnace is exhausted through a number of ports disposed throughout the length of the furnace side walls, each port being equipped with a regulating damper.

The method employed to carry out the heat-treatment process required for these alloy steel ingots is to heat



Courtesy of Wellman Smith Owen Eng. Corp., Ltd.

Fig. 3.—A continuous furnace for normalising and annealing cold-drawn steel tubes. Discharging end ⟶

the furnace and bogie to a temperature of 750° C., which, from cold, normally takes five hours. The door is then raised, the bogie withdrawn, and the furnace charged with a hot case from the electric furnaces, the temperature of the furnace not being allowed to fall below 650° C. before the material enters the furnace. The load is then soaked at the temperature of 650° C. for eight hours. At the end of this soaking period the stock is cooled to a temperature of 300° C. at an average cooling rate of 10° C. per hour, which takes 35 hours, and when at this lower temperature, the material is soaked for six hours. After this step down the material is re-heated as quickly as possible without heating the surface of the ingots above 650° C., this re-heating being effected in eight hours. The material is again soaked at this temperature for eight hours and finally cooled in air after withdrawal from the furnace.

To carry out within reasonably close limits the above temperature time cycle which calls for marked changes in the temperature gradient, it was decided that the nearest approach to the required cycle could only be obtained by equipping the furnace with a programme controller. The furnace was therefore equipped with a model 1550 "Electroflo" automatic programme regulator operating in conjunction with a model 1542 "Electroflo" indicating controller with the control index modified for mechanical connection to cam follower of the programme regulator. The programme regulator is driven by an A.C. synchronous motor and equipped with cam and change gears arranged to give one revolution in 24, 48 and 96 hours. The regulator and temperature controller by means of a relay circuit simultaneously controls the two mechanical stoker motors through the medium of automatic contactor control gear.

The design of these furnaces was influenced by necessity for simplicity and speedy construction caused by war conditions. The performance, however, was most satisfactory and easily met the requirements of the heat-treatment cycle.

Clean Annealing Non-Ferrous Metals

For most processes in the manufacture of non-ferrous metal products annealing operations are necessary and unless this is a finishing operation a clean anneal is desired rather than a bright anneal. Usually this annealing operation is performed in an open fired or muffle type batch furnace, without protective atmosphere, and the scale formed is removed subsequently by pickling. Process annealing of this kind need not be bright, although it should be clean, and for this purpose several furnaces have been installed by British Furnaces Ltd. in which a variety of non-ferrous metals and alloys are being successfully annealed, and the material treated is as clean or cleaner than when charged. One of these furnaces is shown in Fig. 2.

It must be remembered that alloys containing zinc cannot be annealed to give as clean a surface as copper because the annealing temperature is above the temperature at which zinc volatalises and therefore the surface is dulled. But copper, bronze, gunmetal, silver, silver-copper alloy, Monel metal, 70–30 brass, 60–40 brass, and nickel silvers containing 20%, 17% and 7% nickel are suitable materials for clean annealing in the design of furnace mentioned. In the case of copper, bronze, gunmetal, silver or silver-copper alloys, the original standard of cleanliness is maintained or improved through several stages of annealing and rolling, and the finished sheet can be sent out without the need for acid cleaning at any stage in its manufacture, with the exception of scale removal from the ingot as received. Brass, of course, does not retain its original brightness but it is not usually necessary to pickle until all manufacturing processes are finished.

The deep drawing of brass presents a peculiar problem in this respect, as it is found that although it is quite possible to produce clean work without the need to acid pickle, the smooth surface produced by the previous drawing operation does not allow the drawing lubricant to bite. It is usual, therefore, to dip in acid between drawing to facilitate the action of the lubricant.

Nickel silvers of the usual analysis with nickel contents of from 7% to 20% can be annealed after each stage of reduction from the ingot without cleaning, except as a final finishing operation. As a typical instance, in the manufacture of spoon and fork blanks before the installation of this furnace it was usual to give a lengthy treatment in acid to remove scale that had been rolled into the metal. This naturally produced an etched surface. Since the furnace was installed, only a quick dip in acid is required as no scale is formed to roll in, and it is only necessary to remove stains caused by oil, water or zinc, and the surface produced is very much better. The savings effected of course include a reduction in production time and a considerable decrease in metal losses in scale and in acid.

A typical furnace of the type producing this class of work is continuous—the work passing through the furnace on live rollers driven

by chains. The overall length is 37 ft. and the available width 21 inches. The output averages some 900 lbs. per hour of nickel silver with a gas consumption of 825 cu. ft. at a temperature of 750° C.

The rollers of the furnace chamber carry the work between two rows of burners, six firing under the furnaces arch and six being underneath the rollers. The burners are controlled in two zones—the six at the charge end being on one manifold and the six in the soaking zone being on the other. The burner equipment is a decisive factor in the success of this open flame furnace as a clean annealing furnace, as it is only the constant maintenance of near to theoretical combustion conditions that it is possible to prevent discolouration due to either too little or too much air being supplied for combustion.

The burners are of the tunnel type and the tunnels are made in tubes of heat-resisting steel which can be withdrawn from outside the furnace. Thus, it is easy to remake burner tunnels or replace complete burners without waiting for the furnace to cool. The actual heating chamber is 9 ft. long from door to door roughly one third of the total furnace length.

The work emerges from the heating chamber under a baffle door and passes into the cooling chamber. This cooling of the work is done in two stages, the first of which is indirect in that, in this zone heat is extracted by water cooled rollers and banks of pipes above and at the sides of the chamber. The initial cooling is sufficient to bring the work to a temperature well below black heat, but a very long chamber would be required if the temperature were brought down to 60° C.—the temperature above which copper discolours in air, by this method. The furnaces of this type so far built have been provided with direct water sprays playing on to the top and bottom of the work to speed up the cooling and reduce the furnace length.

Towns-gas at the present time usually contains anything from 15 to 30 grains of sulphur per 100 cu. ft., in the form of thiophene mercaptans, etc., and the presence of these reduces the range over which it is possible to produce clean work. If the atmosphere is slightly oxidising the sulphur compounds are burnt to sulphur dioxide, which will not affect the work unless there is excess of oxygen from the air, whereas, if the burners are adjusted to give a reducing atmosphere, the sulphur compounds are present as hydrogen sulphide in the products of combustion and will produce discolouration of the work. It is possible to so adjust the air/gas ratio that neither of these undesirable results is apparent. It has not been considered necessary to remove the sulphur in the furnaces so far installed as the results have been so good that further improvement was not required.

The installations of this type so far completed by British Furnaces Ltd., have shown that most non-ferrous metals can be annealed in the open-fired furnace, to give a surface finish which, without special cleaning of the metal will be substantially better than that generally obtained by the more usual methods. If it is necessary to pickle the work, the time required and the losses in metal and acid are but a fraction of those inseparable from the usual open or muffle fixed annealing furnace.

Finally, if the work is cleaned prior to annealing, it is possible to produce clean and bright work from the furnace, a finish that is quite satisfactory as a finishing operation without any need for an acid dip.

A Normalising and Annealing Tube Furnace

Furnace designers to-day must not only be familiar with many phases of metallurgy, heat-treatment and fuel technology, but must appreciate the manufacturing conditions and processes of a particular industry in which a furnace is to operate. The heat-treatment of tubes, for instance, can be effected by the batch process, or by a continuous process, depending upon the ratio of volume to weight when handling tubes in bundles, and other considerations. The continuous furnace, shown in Fig. 3, was specially designed by The Wellman Smith Owen Engineering Corporation for normalising and annealing cold drawn steel tubes of 0·1–0·4 carbon, containing up to 1% nickel, in sizes from 1 $\frac{1}{16}$ in. to 5 in. outside diameter of varying wall thickness, the tubes varying in length from 6 ft. to 35 ft.

The furnace is capable of giving an output of three tons per hour when handling tubes 2 in. outside diameter with a wall thickness of 10 gauge and a normal length of 18 ft., heat-treated from cold to 950° C., soaked at 950° C., and cooled to 400° C., the other duties of the furnace varying according to the size and wall thickness of the tubes being handled. The fuel used is raw coke producer gas.

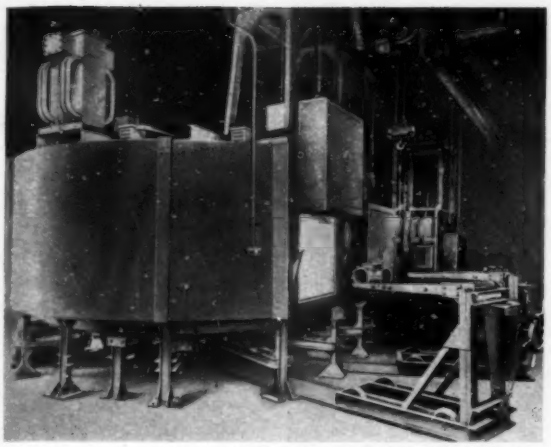
The total overall length of the furnace proper is 76 ft., of which the heating and soaking zones combined occupy 35 ft. 11 in., the remaining 40 ft. 8 in. constituting a cooling chamber. The effective width of the furnace between the guide blocks is 3 ft. 6 in., the heating and soaking chamber being 4 ft. between the side walls and arranged for both over and under firing of the tubes, combustion being effected by means of "Basequip K" type gas burners which give a neutral or reducing atmosphere in the furnace. To effect economy in fuel consumption the air for combustion is preheated by a "Newton" needle type recuperator, and the gas supply main to the furnace is lagged with heat insulating material.

The furnace heating and soaking chamber is provided with heat-resisting steel rollers each mounted upon a water cooled shaft. The cooling chamber is provided with water cooled rollers between each of which is a static water cooled tube set 1 in. below the level of the rollers. That part of the cooling chamber adjacent to the soaking chamber is lined with refractory and insulating material, but towards the discharge end of the cooling chamber, in addition to the cooling equipment described above, cooling of this chamber is also effected by water trays forming the roof of the chamber. The distribution of cooling water to these parts is so arranged that the supply can be cut off from various sections as desired to control the temperature gradient and suit the heat-treatment cycle being carried out.

The furnace is equipped with a three-point recording pyrometer and a recording controller arranged to control motorised units fitted with a cam and provided with link gear to the gas and air regulating valves which enables the temperature of the furnace to be controlled within close limits of the temperature at which the controller is set.

The furnace has been in operation for some time and tubes tested at regular intervals for tensile strength and elongation were found entirely satisfactory, including those on tubes passed through the furnace at the highest rate of through-put.

A more specialised design of furnace plant is shown in Fig. 4. It is installed at the Wellington works of Joseph



Courtesy of G. W. B. Electric Furnaces, Ltd.

Fig. 4.—Heat-treatment plant for welded air-screw barrels at the Hadley Castle Works of Joseph Sankey & Sons, Ltd. In the foreground is a rotary hearth furnace used for normalising at 850° C. after the barrel halves have been butt welded. After slow air cooling the barrels are reheated to 840° C. in the same furnace and quenched in cold oil to give the requisite hardness. The barrels are finally tempered at 650° C. in the continuous slat conveyor furnace shown in the background.

Sankey & Sons, Ltd., for the heat-treatment of welded air-screw barrels. The furnace shown in the foreground is of the rotary hearth type and is used for normalising at 850° C., after the barrel halves have been butt welded together. After slow air cooling, the barrels are reheated to 840° C. in the same furnace, and quenched in cold supergrade oil to give the requisite hardening; the barrels are finally tempered at 650° C. in the continuous slat conveyor furnace shown in the background of the illustration.

Bright Annealing

The demand for continuous furnaces for modern production methods has resulted in the development of simply operated furnaces of clean and neat appearance, for incorporation in production lines. Belt conveyors are ideal for many heat applications in mass production, as they are capable of continuously treating large quantities of varied shape charge. These furnaces are very suitable for use with protective atmospheres and are being increasingly employed for bright annealing, sintering and brazing. When an artificial atmosphere is used, as in Fig. 5, the conveyor and charge usually travels through a gas-tight duct which not only reduces the volume of gas required but also avoids the necessity for a gas-tight furnace chamber. Automatic feeders recently developed greatly simplify loading of these conveyor furnaces. The example shown is designed for bright annealing steel plates.

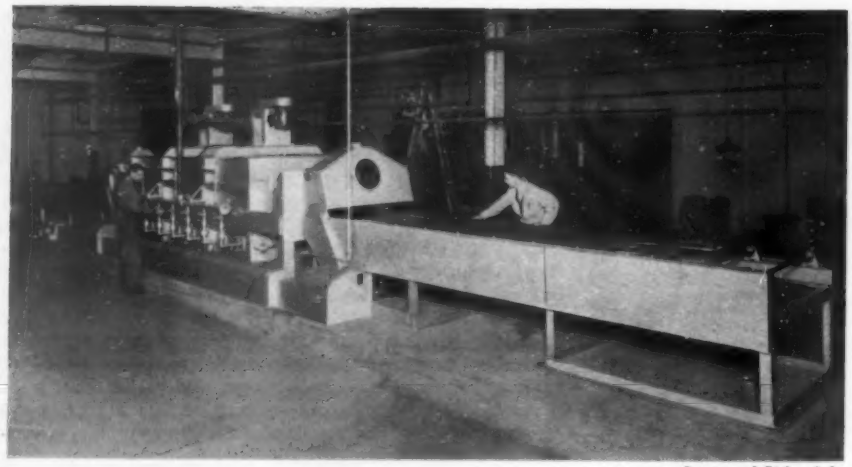
An improvement in economy of operation and capital cost of continuous conveyor furnaces for this kind of treatment, where coal-gas is available, is the new Birlec furnace, of which an example in the roller-hearth form is shown in Fig. 6. This installation is for the continuous bright annealing of copper tubes and is heated by open-type, direct-fired gas burners. The non-oxidising atmosphere of the furnace is maintained by the combustion products of the burners, the composition of which is closely controlled to give the desired results. Circulating fans are mounted in the heating chamber to assist uniform temperature distribution and rapid heating of the work. An important feature of the design is the arrangement for passing the material through a water-spray section immediately following the heating chamber. By this means, the long water-jacketed cooling chamber, usually associated with continuous bright annealing furnaces, is avoided and the overall length as well as the cost of installation is correspondingly reduced.

This design eliminates the need for a separate atmosphere generating plant, yet it enables a bright finish to be obtained on any material for which an approximately neutral atmosphere is suitable. In most cases ferrous materials require a reducing atmosphere which cannot be obtained with efficient combustion for heating in this type of furnace.

Another interesting installation of this type is shown in Fig. 7. In this instance the recently developed Spiro-Ray method of radiant heating is applied. For controlled atmosphere processing work radiant tube heating is now established furnace practice, but until the development of the Spiro-Ray system it had been difficult to apply to furnace chambers of very small or very large dimen-

Courtesy of G. W. B. Electric Furnaces, Ltd.

Fig. 5.—Mesh-belt conveyor furnace for the bright annealing of steel plates—treated plates are shown in the foreground. The charge travels through a preheating purging chamber, heating chamber and cooling chamber, protected against oxidation by an atmosphere of partially combusted towns-gas.



Courtesy of Birlec, Ltd.

Fig. 6.—Continuous roller-hearth gas-fired furnace for bright annealing.

sions, because of the limitations imposed by the use of straight tubes . . . when using short straight tubes the time element is insufficient for satisfactory heat release by radiation, and for large furnaces, constructional factors limit the desired length of tube and consequently the capacity.

The Spiro-Ray system of firing is based on the use of coiled radiant tubes built into a furnace chamber of circular or oval cross-section, arranged either vertically or horizontally, according to requirements. The unit coil length is chosen on the basis of thermal efficiency, and any number of coils can be used to accommodate tonnage and dimensional demands. This system of heating can be applied to most other forms of heat-treatment.

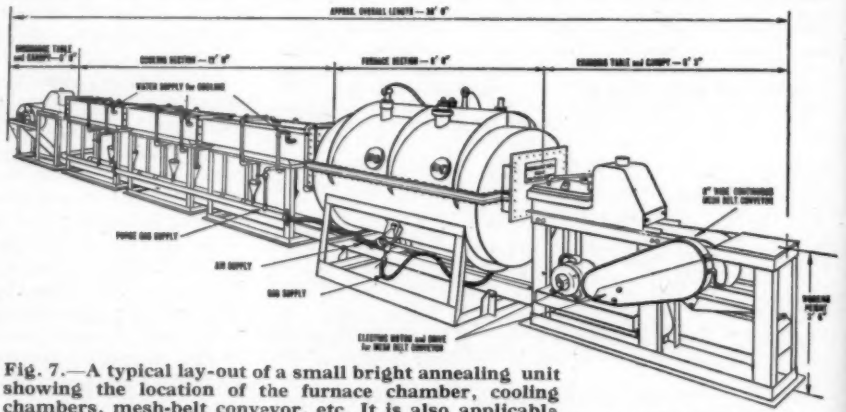


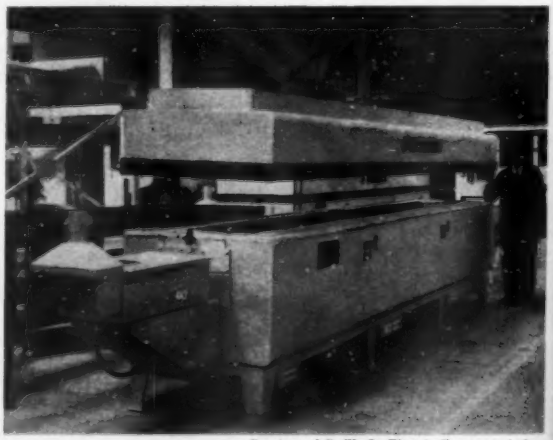
Fig. 7.—A typical lay-out of a small bright annealing unit showing the location of the furnace chamber, cooling chambers, mesh-belt conveyor, etc. It is also applicable as a bright copper brazing unit.

Courtesy of The Incandescent Heat Co., Ltd.

Efforts have been made to reduce the height of the heating chamber in continuous furnaces, primarily to localise the heat for economy in operation, but the question of inspection with a view to proper maintenance has been a problem. Of particular interest in this respect is the continuous furnace for bright annealing, cleaning, hardening and tempering alloy steel strip shown in Fig. 8. As will be seen, it has a removable roof which permits inspection and enables the size of heating chamber to be reduced to a minimum. This furnace, which is designed and constructed by G. W. B. Electric Furnaces, Ltd., is a "pull through" type, and similar constructed furnaces are used for the heat-treatment of wire. The charge travels through a duct or muffle, within which a suitable protective atmosphere is circulated.

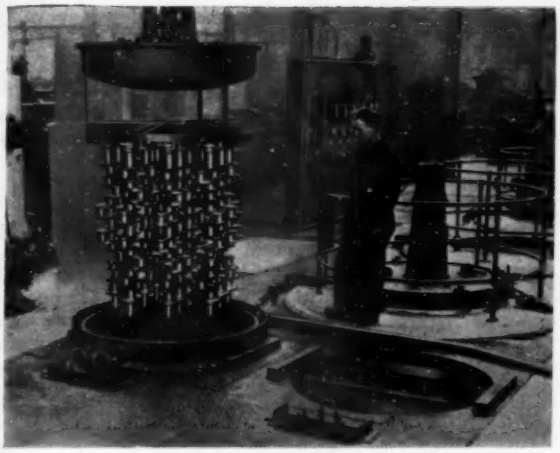
Not all furnaces for this class of work are of the continuous type, indeed for many kinds of finished components, and for strip and wire, batch furnaces are in general use. Of these the vertical cylindrical type is very popular. Probably the chief reasons for this popularity are that heat is applied to the charge concentrically, which makes for uniformity of heating and treatment, and the fact that these furnaces can be fitted with a means of closure which is simple, efficient and very effective. They are ideal for the treatment of strip or wire in coils and for most processes which call for the use of an artificial gas atmosphere, as in bright annealing.

In these furnaces the charge of coils is stacked up on a heat-resisting base casting which is suspended from the underside of the head of a pot made of light



Courtesy of G. W. B. Electric Furnaces, Ltd.

Fig. 8.—Continuous furnace for the bright annealing, clean hardening and tempering alloy steel strip. It is a "pull through" type and similarly constructed furnaces are used for the heat-treatment of wire. The charge travels through a dust or muffle, within which a suitable protective atmosphere is circulated. Of particular interest is the removable roof which permits inspection and enables the size of heating chamber to be reduced to a minimum.



Courtesy of The General Electric Co., Ltd

Fig. 9.—Vertical Cylindrical nitriding furnaces for engine crankshafts.

heat-resisting sheet. The fact that the pot does not carry the weight of the charge but merely functions as an atmosphere container and atmospheric oxygen excluder enables it to be made of light gauge material with but little thermal capacity ; this, in turn, reduces the weight of extraneous metal to be heated and consequently increases the thermal efficiency of the whole plant and process. This efficiency is still further improved by a system of heat recuperation by which new charges are preheated by heat given off by hot pots after they have finished the heating cycle in the furnace. The gas atmosphere used varies with the material treated but is, in all cases, used with an economy which is not attainable with other types of furnace. The anneal obtained is exceptionally good and very consistent. With uniform charges a uniform time cycle can be adopted and this, combined with other features makes for a very marked economy in labour and a reduced dependence upon the skill and attention of what labour is required.

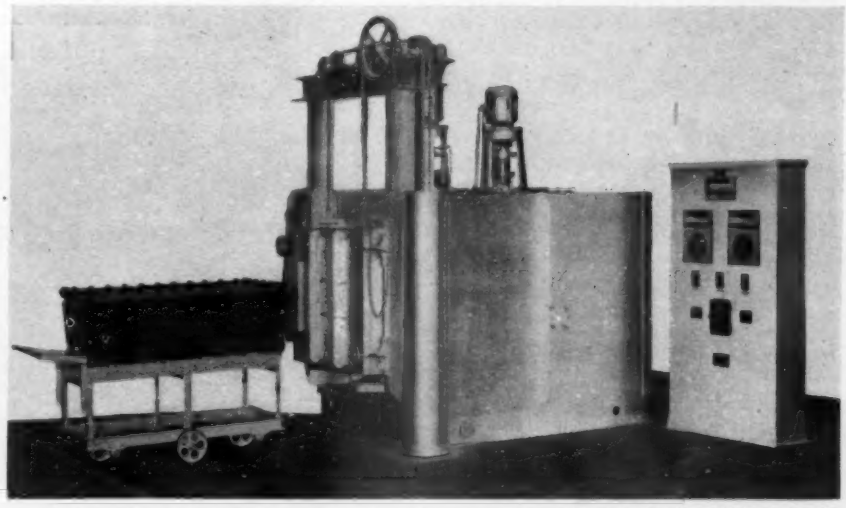
Nitriding

This same general type of furnace has been adapted for nitriding or the surface hardening of special steels by heating in an atmosphere derived from ammonia, which gives an exceptionally hard case, the depth of which is generally proportionate to the length of the heating period. Many such furnaces are used for nitriding crankshafts which are suspended from the underside of the pot head, as is shown in Fig. 9, with the result that distortion is practically eliminated. Others are used for nitriding the cylinder liners of a well-known aircraft engine. The parts which are surface hardened by the nitriding process are of such delicate design and proportions that the greatest care has to be taken in supporting them in the furnace so as to avoid any possibility of distortion. This is achieved by loading the pieces on a special heat-resisting charge support assembly which dispenses with the use of jigs which would otherwise be required. A typical box type nitriding furnace is shown in Fig. 10.

Carburising

During recent years considerable attention has been given to the use of gas as a suitable medium for carburising the surfaces of steel parts required to be hard and wear-resisting, while retaining a tough interior. The use of a suitable gas offers distinct advantages since it reduces the high labour costs associated with the use of the pack method and it is applicable to the whole range of case depths covered by other methods. The method offers greater possibilities of control and enables carburising to be effected uniformly for the thinnest case.

Equipment for gas carburising permits that degree of accuracy which is generally associated with precision tools and of the furnaces designed for this form of treatment particular interest is associated with the Homocarb method of Leeds & Northrop Co., the equipment for which is made in this country by The Integra Co., Ltd. With this equipment it is claimed that each component in a charge is heated to the same temperature, in the same quality and quantity of carburising gas, for the same length of time, and that the control over these factors enables the work to be treated successfully. The complete equipment includes the furnace, with retort, heater, fan, fan motor, lid lifter, thermocouple and operator's protecting shield ; it may also include work baskets or trays for supporting the work in the furnace ; the instrument panel, with indicator and controller, and contactor cabinet. An injecting pump forms part of the assembly, from which Homocarb fluid in regular quantities is supplied to the furnace to provide the quantity and quality of carburising gas in contact with the work being treated. At any point in the cycle, test pieces can be inserted or removed simply by opening a



Courtesy of The General Electric Co., Ltd.

Fig. 10.—Typical box type nitriding furnace.

Courtesy of Birlec, Ltd,

Fig. 11.—Vertical stationary type gas carburising furnace.

hinged cap on the furnace lid. Such test specimens, quenched, broken and etched before the load is removed, can be of great value in checking the case depth of unfamiliar steels or parts, in order to establish the cycle.

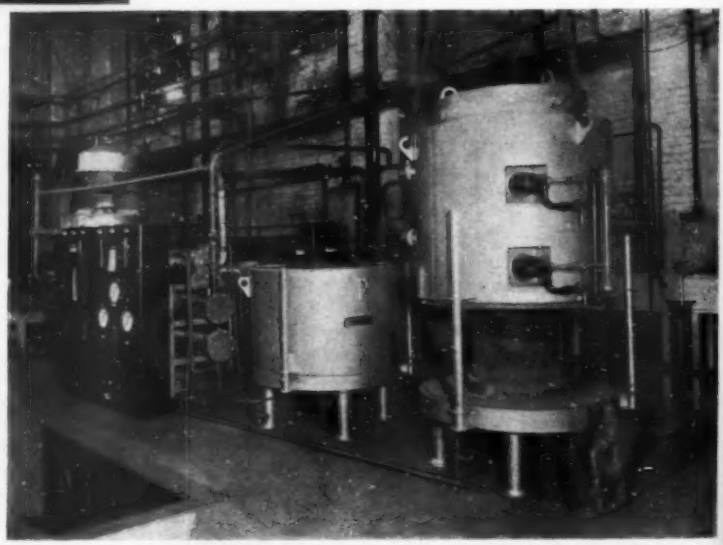
Birlec Ltd. have also perfected a process of gas carburising steel parts. The furnaces used are of the vertical cylindrical type, as shown in Fig. 11, fitted with radiant heating elements on the inner face of the chamber lining and a gas-tight, heat-resisting retort or container mounted vertically within the chamber. The retort is provided with a gas-tight cover at the top, set in a granular refractory seal and a powerful motor driven fan is located on the bottom of the container. Work is loaded in a cylindrical basket, or fixture, which is lowered into the retort. The fan circulates the atmosphere of the retort continuously and rapidly throughout the charge, thereby promoting rapid and uniform heating and an even distribution of the carburising effect. Where quenching is not required, the work is quickly transferred by an overhead hoist from the retort into a gas-tight cooling chamber which may be water-jacketed to give accelerated cooling. The atmosphere is derived from ordinary towns-gas which is passed through a special plant to adjust its composition suitably. Ordinary coal-gas may also be used to maintain non-oxidising, non-decarborising conditions in the cooling chamber.

An alternative type of furnace is offered by this firm for certain kinds of small articles and in this case the furnace normally operates in a horizontal position, the retort being continually rotated. By this means, uniform heating and intimate gas contact with all parts of the charge are obtained without the use of a fan, while the discharge of the work directly into a quench tank is facilitated by mounting the furnace on trunnions so that it can be tilted after removing the retort plug.

A complete installation for gas carburising is shown in Fig 12. It is designed by The Incandescent Heat Co., Ltd., the gas plant for which has already been described.*

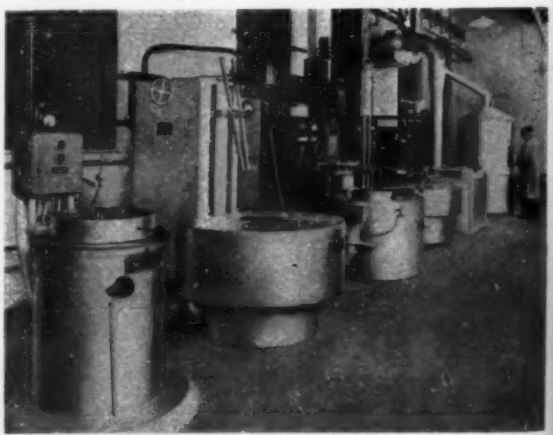
The Spiro-Ray system of heating is used in this furnace, which is suitable for a loading capacity per charge up to 300 lbs. The complete equipment comprises: one Spiro-Ray cell furnace and cover, the furnace and cover having the necessary lifting attachments for loading and transfer; three bases, each with circulating fan and alloy steel basket; three open top type inner covers; three dome top type inner covers; three nickel-chrome alloy loading jigs; one small constant pressure blowing fan and starter; one master control panel mounting draught gauges, gas flow indicators, indicating temperature controller, temperature recorder, signal lamps, etc.; thermocouples, compensating leads and motorised valves and links for

* METALLURGIA, April, 1946, pp. 317–319.



Courtesy of The Incandescent Heat Co., Ltd.

Fig. 12.—A complete installation for gas carburising steel parts.



Courtesy of The General Electric Co., Ltd.

Fig. 13.—Complete electric tool hardening equipment, including electrode type salt bath furnaces, cyanide bath and forced air circulation tool room, tempering furnace.

the instruments on the panel ; and a standard unit type gas plant.

Hardening and Tempering

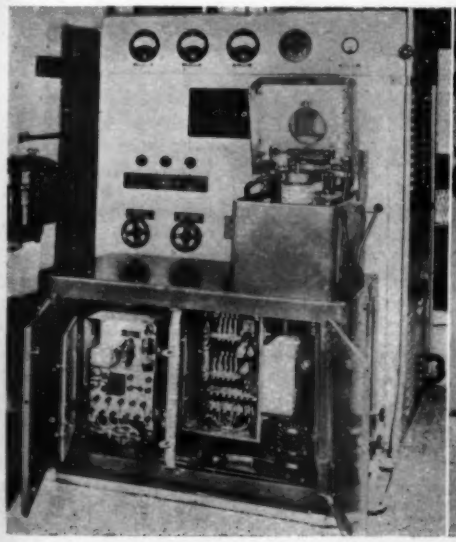
Several types of furnaces are available for hardening and tempering and for this work electrode type salt bath furnaces have grown in popularity in recent years. High temperature furnaces are used chiefly for hardening high speed steel tools at temperatures between 1,200 and 1,400° C. Low temperature salt baths are used for pre-heating high speed steel tools before they are immersed in the high temperature bath, for hot-quenching some tools after withdrawal from the hardening furnace and for hardening carbon steel tools. They are also used for the cyanide hardening of small steel components and for some brazing jobs. The low temperature salt baths usually work at temperatures varying from 500 to 1,000° C. In both types of salt bath furnace tools are heated very rapidly with a total absence of scaling which tends to destroy fine cutting edges. A representative furnace for tool hardening is shown in Fig. 13.

Light Alloy Heat-treatment

Furnaces for the heat-treatment of light alloys have developed considerably in recent years. These furnaces are essentially of the low temperature group, being used mainly for pre-heating at around 520° C. prior to extrusion or rolling ; annealing, usually within the temperature range 340–400° C ; solution heat-treatment ; heating to a prescribed temperature (495–525° C) followed by rapid quenching in oil or water to increase the strength of the alloy ; and ageing, by soaking in a temperature of 100–200° C. the ageing time required to reach maximum strength after solution heat-treatment is from 5 to 20 hours. Normal ageing at room temperature requires about 5 days. For the pre-heating of billets and slabs, conveyor and pusher furnaces are extensively used. The heat transfer is obtained by artificial convection currents which promote rapid initial heating and uniformity of temperature, radiation being inefficient at low and medium temperatures. Constant air circulation is maintained by the centrifugal fans fitted in the roof in G. W. B. installations, the air being forced through the element chambers and drawn back through the charge. The billets are loaded by the electrically operated hoist on to a serrated continuous roller chain. The door gear is interlocked with the hoist, to open automatically when the billet is ready to enter. Having passed through the furnace, the billets are discharged down a ramp into a trough adjacent to the extrusion press. The discharge door gear is operated by adjustable trips on the conveyor driving shaft. For the treatment of varying size charges, or others that may not be contained by the serrated chain links, V shaped trays or slats are fitted to the chain. Pusher furnaces, similar in construction and application to the conveyor furnaces, are used mainly for slab heating. The slabs are conveyed upon cast shoes which are passed through the furnace over idler rollers, by an electric ram ; the charge thereby, not being subjected to abrasion or compression. Once again, the doors are interlocked with the pusher. An automatic discharge gear, which may also be interlocked, withdraws the charge from the furnace, removes the slabs from the shoes and places them in a horizontal position upon a roller discharge table. The shoes are then returned by a gravity conveyor to the charging end. Billets may be conveyed upon diablo shaped idler rollers and discharged either down a ramp or by means of a suitable number of driven rollers.

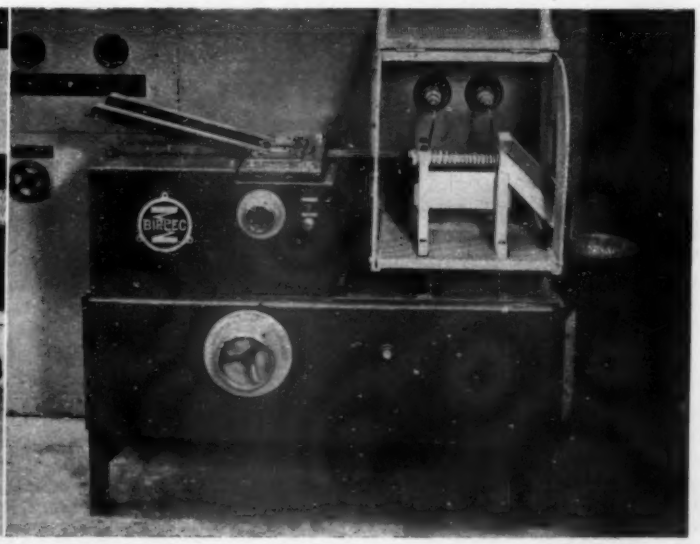
Both conveyor and pusher furnaces, being often of considerable length, are divided into independent, automatically controlled heating zones, to compensate for uneven loading or similar conditions and to maintain steady temperature for the required heating cycle.

Tubular furnaces are commonly used for annealing and ageing. Again, the heat is transmitted mainly by convection currents created by a high velocity system which give an extremely uniform temperature. The centrifugal multi-blade fan unit is usually at the rear of the furnace but for comparatively long chambers, series of vertical fans are situated in the roof.



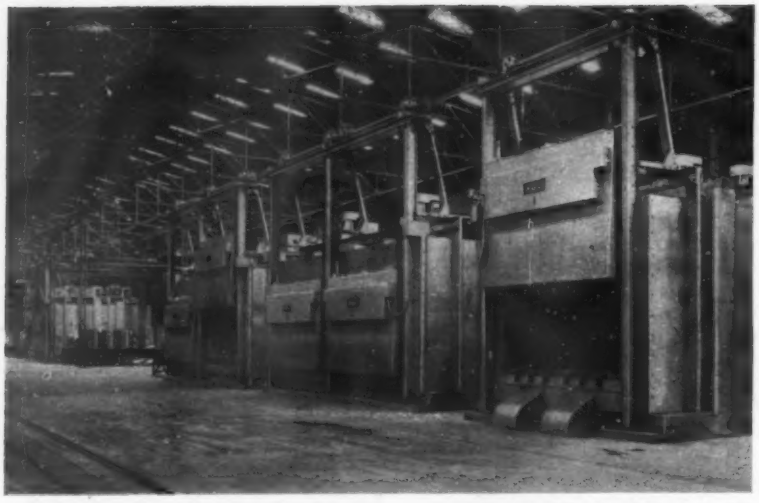
Courtesy of Birlec, Ltd.

Fig. 14.—High-frequency valve oscillator with inductor and timing gear for hardening small gears, etc.



Courtesy of Birlec, Ltd.

Fig. 15.—Continuous feeding and heating mechanism for small steel billets connected to valve type oscillator.



Courtesy of The General Electric Co., Ltd.

Fig. 16.—Typical installation of batch type furnaces comprising three twin chamber 720 kw. furnaces and one 300 kw. mechanical hearth furnace.

Fabricated articulated skips, which accommodate practically any type of charge, are propelled over idler rollers by a charging machine. The charger, which is of the in-out type, fitted with a grab to locate on the skips, may be hand or electrically operated, dependent upon the load and speeds required. Duplex traversing machines, used in conjunction with loading tables, greatly reduce the time required for charging.

The tubular type furnace is particularly suitable for the solution heat-treatment of light alloys. A quench tank is in line with the furnace, before the door ; a table fitted with idler rollers in line with those in the furnace is supported within the anti-splash kerbs lining the tank. The skips are discharged directly upon the table by means of a bridge-type semi-automatic grab, and are lowered into the tank controlled by a centrifugal governor ; this operation is achieved in a very few seconds. When the table and loaded skips have ascended, the skips with quenched charge are removed by a duplex charging machine and a fresh charge placed into the furnace. Visual signals and interlocked charging and quench hoist gear prevent the possibility of damage due to human carelessness.

High-Frequency Induction Heating

A more recent means of applying heat, by means of high-frequency induction, has been described previously, but Birlec activities in this direction are considerable ; the type of equipment produced, however, is so diverse that a brief description is difficult. Briefly, two main types of high-frequency power generator, or convertor, are employed—namely :—

(*a*) Motor driven rotary alternators supplying power at frequencies generally between 1,000 and 10,000 cycles per second and with power outputs ranging up to 500 k.w., or larger.

(*b*) Thermionic-valve oscillators supplying power at frequencies usually between 100,000 and 10,000,000 cycles per second with output capacities at present limited by available valves to a maximum of some 40 or 50 k.w.

The rotary alternator is usually associated with equipment for through-heating and for heavy heating loads and large production requirements. The heating of bolts and /or bar-stock for forging and the localised heat-treatment of various automobile and other machine parts, are common fields of application while the melting of alloy steels is another well-known and long established operation for induction heating.

The valve-type generators, by virtue of the higher frequency range available, are often used where it is desired to exploit the skin effect of high-frequency currents. This phenomenon enables the surface of a steel article to be heated and quenched so rapidly that it may be fully hardened to a depth of a few thousandths of an inch without affecting the interior of the piece. An example of this type is shown in Fig. 14, while continuous feeding and heating mechanism for small steel billets is shown in Fig. 15.

Associated with either type of convertor may be a variety of automatic handling mechanisms for delivering the material into the inductor-coil and /or quenching spray and for controlling the time of application of heat and cooling medium respectively. Rediffusion, Ltd., have carried out considerable experimental work in this field and have been successful in applying the process to a wide variety of products required on a quantity basis.

Developments in Furnace Design

Apart from the usual general purpose batch-type furnaces for carburising, annealing, hardening, tempering and nitriding, many are designed for particular service. A recent installation by G. W. B. Electric Furnaces, Ltd., is designed for annealing large light alloy sheets, which are hung vertically from an overhead charge carrier. A high velocity air circulation system is incorporated, giving a rapid initial heating and a high degree of temperature uniformity.

The popular impression of batch type furnaces is more or less confined to those having a horizontal hearth and which are rectangular in plan with a door at one end. A large number of such furnaces has been installed during recent years, some of which are 20 to 30 ft. long with electrical loadings as high as 300 to 500 k.w. They are used for a very wide range of purposes, including annealing, hardening and general heat-treatment of both ferrous and non-ferrous metals and alloys. Many of those used for heat-treating non-ferrous metals and alloys and which work at moderate temperatures are fitted with power-driven fans which facilitate quick equalisation of temperature throughout the charge. A battery of large twin-chamber batch furnaces installed by G. E. C., Ltd., is shown in Fig. 16. Most of the larger furnaces of this type are provided with some mechanical means of charging, usually an electrically operated machine which works in conjunction with a slotted hearth.

Batch furnaces for hardening and tempering alloy steel bars 18 ft. long were recently installed by G. W. B. Electric Furnaces, Ltd. These furnaces are identical, and, being fitted with heat-resisting water-cooled fan units, are interchangeable for either process. The charge,

loaded upon heat-resisting alloy steel carriers, is withdrawn from the furnace and placed upon the quench tank platforms, shown centrally between the furnaces, by a special high-speed charging machine. These platforms rest upon stops which withdraw when the charge is in position; the descent and ascent are operated by an electric winch, the control being in a convenient position. Safety devices ensure that the charging machine and quench gear are unable to operate in incorrect sequence; the platform is guided within the tank, in all positions.

Reference has been made to some type of continuous furnaces. In addition to the conveyor and pusher types however, the following types have been developed and improved to suit modern conditions. Rotary hearth, walking beam hearth, and the reciprocating or "Shaker" hearth type. All these are now suitable for use with protective atmosphere and the handling at loading and unloading points has been simplified.

Rotary hearth furnaces comprise a hearth of annular construction revolving in a stationary chamber. This method gives a long heating length in a comparatively small floor space, and also allows for the loading and unloading points to be adjacent. Small chamber furnaces have a lowering hearth, which permits easy inspection of the furnace interior.

The walking beam furnace has been applied to normalising, annealing and many other applications. Hearth beams, a number of which move with an elliptical or rectangular motion may be refractory lined and insulated, or of heat-resisting alloy. The latter type beams operate above the hearth lining and are not part of the hearth proper.

A recently perfected design of the reciprocating hearth, or "shaker" furnace, has overcome the rather noisy jerky movement that has been an undesirable feature of these units in the past. The hearth is in the form of a tray, the shape of the tray being of major importance, and designed for the controlled consistent travel of certain shape charges. One end of the tray is oscillated by a cranked gear, the tray being free to expand within locating guides. Pivoted supports for the tray are arranged at an angle from the horizontal so that the tray is dead level at all times and a rhythmic motion is achieved. This furnace is suitable for the heat-treatment of bolts, screws, small castings, pressings and blanks. It should be noted that for the rotary hearth, walking hearth and shaker hearth furnaces, the conveying medium remains within the heating chamber, thereby increasing the thermal efficiency.

In recent years attention has also been given to furnace hearths. The advantages of metallic hearths for heat-treatment furnaces are now realised by the use of small tiles by which distortion is avoided. A recent development of this type is the patent Incandescent "Nicrotectile" furnace hearth in which the hearth is formed by a series of small heat-resisting tiles positively interlocked in all places in such a manner that the tiles cannot be displaced even when subjected to rough handling.

Brazing Furnaces

For some years developments in furnace design and construction have made possible the brazing of components and both batch and continuous type furnaces are being used for this purpose. It is not surprising that

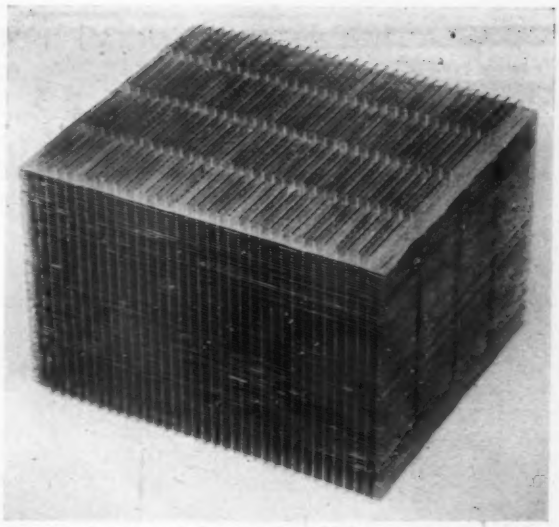
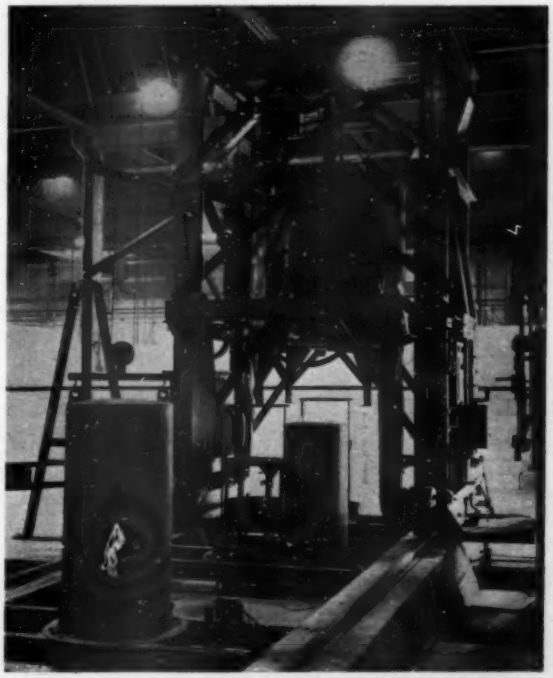


Fig. 17. An aircraft intercooler, 21 in. × 15 in. × 12 in.

during the war many furnaces were further developed for this special heat-treatment purpose, which for security reasons have not been published. An interesting development of this kind concerned the construction of aircraft intercoolers, a brief description of which will be of interest.

It was found necessary to produce special aircraft intercoolers for use between the superchargers and the engine, to increase the engine efficiency and hence an



Courtesy of Wild-Barfield Electric Furnaces, Ltd.

Fig. 18.—Bell-base furnace installation for brazing the assembly.

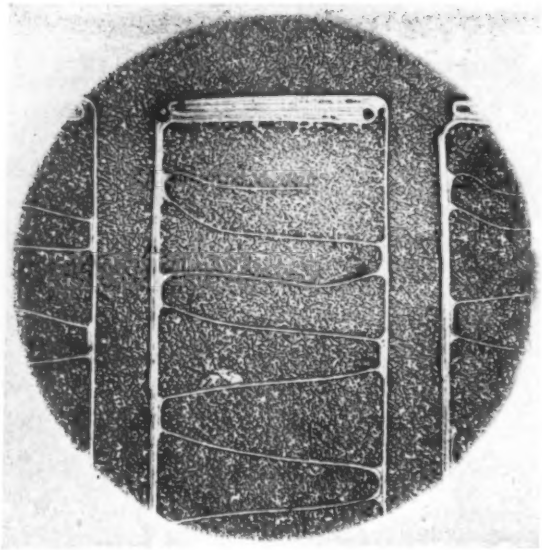


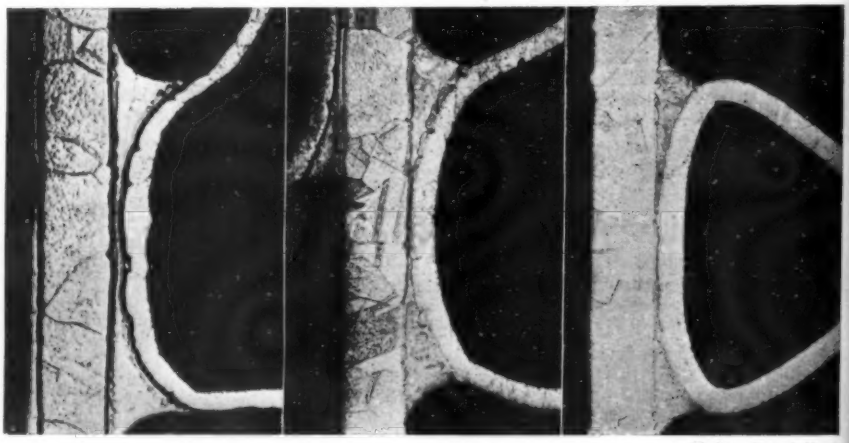
Fig. 19.—Photomicrograph of section, mounted in a low melting alloy, showing a portion of one of the tubes with internal copper stiffeners. × 6.5

enhanced ceiling, owing to the fact that the conventional solder-dipped type had such a short life due to the pressure and temperatures obtaining in the intercooler. Bearing in mind the essential requirements of an intercooler, the materials finally chosen were copper and silver, in the form of silver-clad copper sheets, from which the separate components as tubes, fins, gills and stiffeners were produced. Initially silver-plated copper components were employed, but these were not so successful as the silver-clad material. It was essential also to employ oxygen-free high conductivity copper, as the assembly, when jigged, was brazed in a controlled atmosphere of cracked ammonia (75% H_2 and 25% N_2).

Reference to the copper-silver equilibrium diagram shows that a eutectic exists composed of approximately 72% Ag and 28% Cu with a eutectic temperature of 778° C., the latest figures according to D. Stockdale* are 71·94% Ag, 28·1% Cu and 779·4 ± 0·1° C. These simple facts were the basis of all the work on the silver-clad copper intercooler.

A unit similar to that shown in Fig. 17 (21 in. × 15 in. × 12 in.) was very carefully assembled and then lightly jigged, after which it was brazed in the bell-base furnace installation, Fig. 18, at 800° C. using an atmosphere of cracked ammonia, being given from 5–10 minutes soak at this temperature. During this operation, which is above the eutectic temperature, brazing of the various parts takes place. The furnace installation was designed specifically for the brazing of intercoolers and has many novel features, such as, all metal base entirely free from refractories; water-cooled mercury seal between the base cover and the base itself; and completely self-contained furnace on a structure complete with all electrical controls, transformers, contactors, switch-gear, etc., and fitted with limit switches and every device to ensure easy and fool-proof operation. The complete furnace plant is controlled by the operator working from the platform seen on the extreme right of Fig. 18, and the atmosphere is provided from one 5M³/hr. cracker, piped through separate flowmeters to each base. After the soaking period the furnace is removed and the intercooler allowed to cool down normally under the controlled atmosphere.

The efficacy of the joint, which has to withstand temperatures up to 250° C. and pressure up to 50 lbs./sq. in. is shown by reference to Figs. 19, 20, 21, 22 and 23, which show the results obtained. It is noteworthy that the approximate number of joints brazed in an intercooler of the dimensions indicated was 12,500 and that when careful attention was paid to correct materials and assembly, the unit was entirely satisfactory.



Reduced to ⅓ linear.

Figs. 20, 21 and 22.—Photomicrographs of sections showing the quality of brazing in joints between the inner wall of a tube and stiffener. × 80.

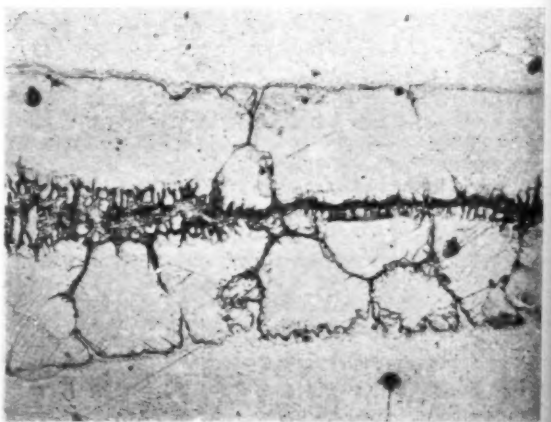
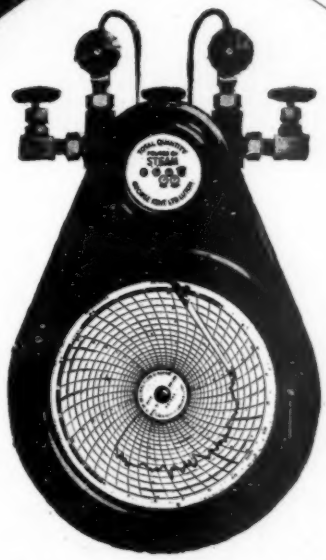


Fig. 23.—Photomicrograph showing an enlarged view of one of the joints of the intercooler. × 140

* "The Composition of Eutectics," *J. Inst. Metals*, 1930, Vol. 43, pp. 193.



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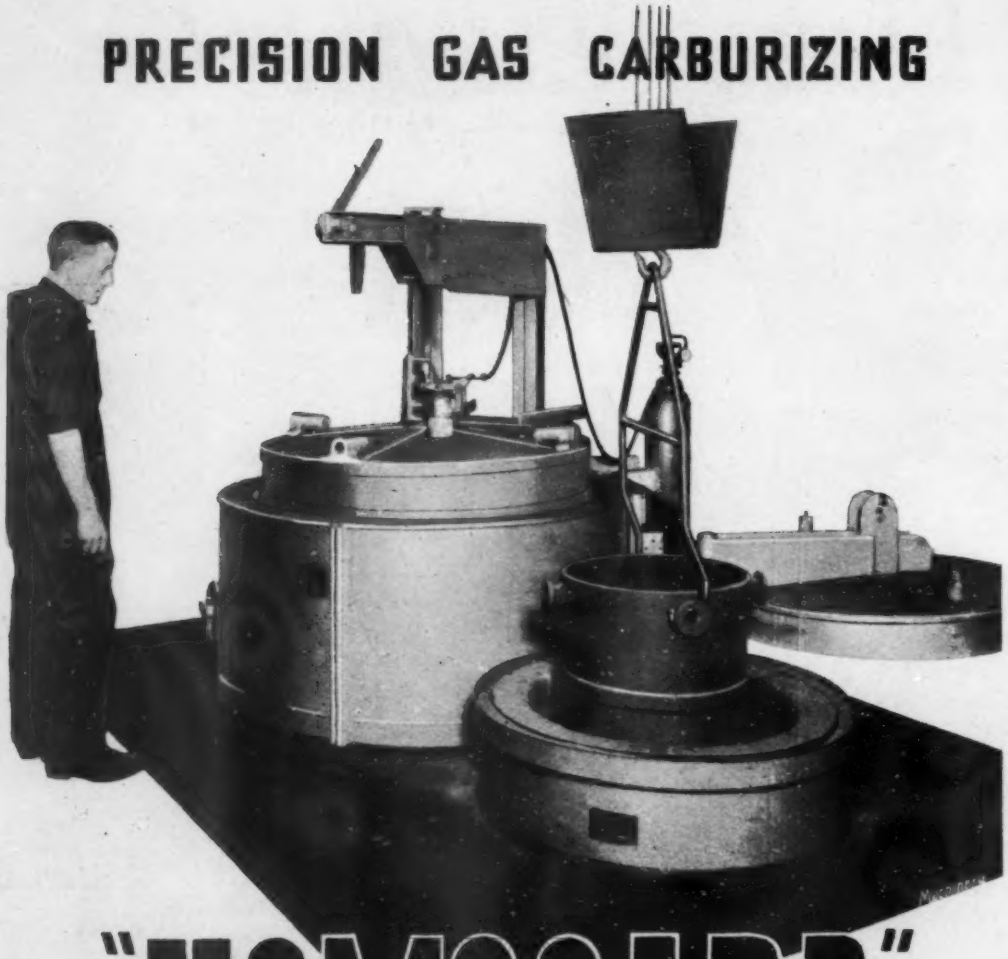

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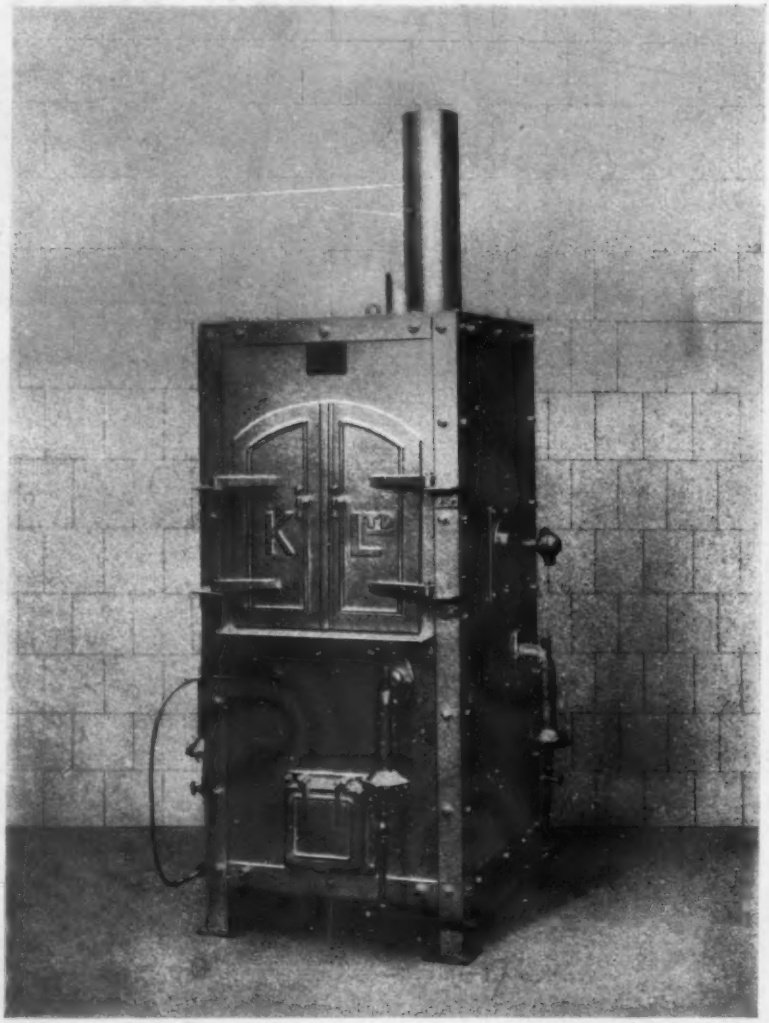

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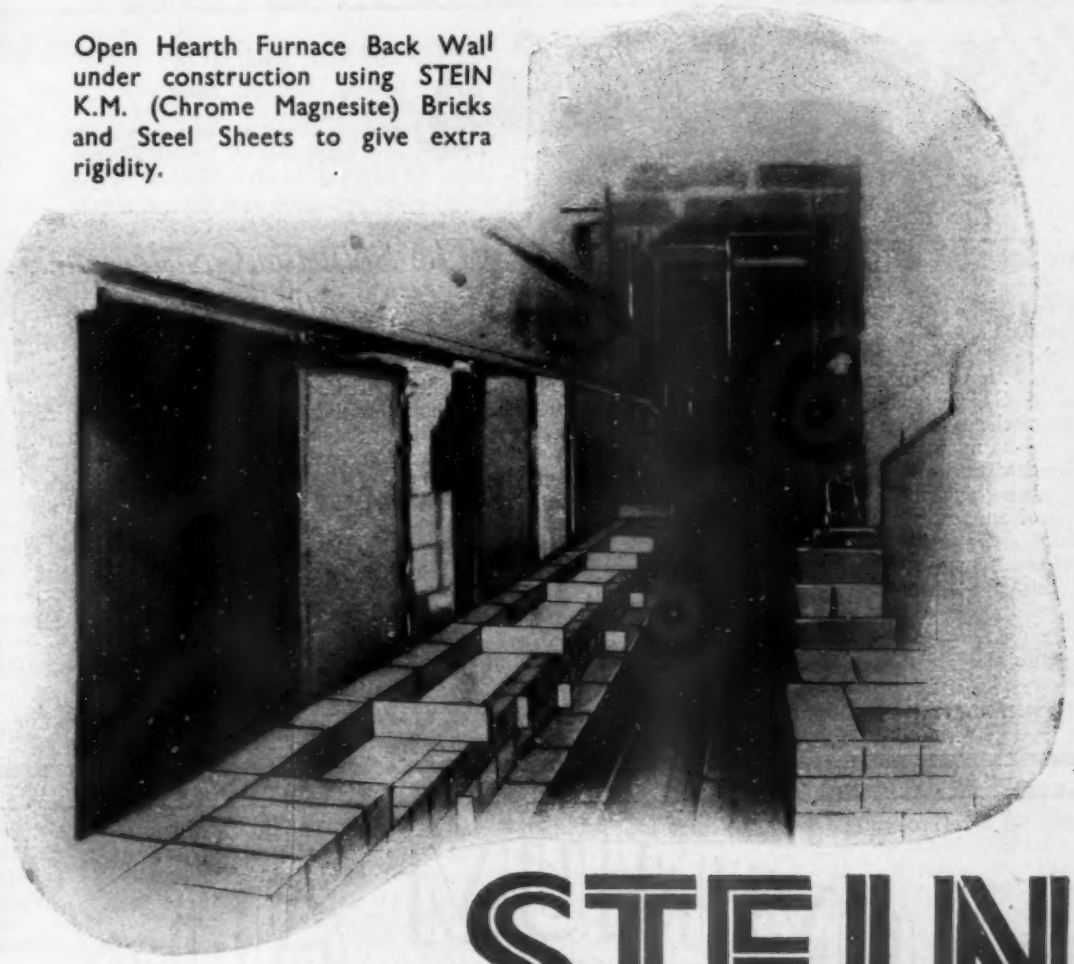

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The Iron and Steel Institute

Annual General Meeting Held in London

This meeting provided happy evidence that the war is over. In addition to many members from the Dominions and foreign countries, home members were present in greater numbers than has been possible during the war years. In addition the spirit and enthusiasm shown was of a high order, despite the many difficulties before the industry, which should be a happy augury for the future. It is only possible here to give an outline of the proceedings and to summarise the papers presented at the technical sessions.

THE seventy-seventh annual general meeting of the above Institute was held at the Offices of the Institute, on May 1 and 2, 1946, with Mr. Arthur Dorman, retiring President, in the Chair during the early part of the proceedings, and subsequently by Dr. C. H. Desch, F.R.S., the new President. The initial meeting was crowded with members, the numbers attending and the enthusiasm displayed being reminiscent of pre-war meetings.

Following the acceptance of the minutes of the previous meeting, Mr. Dorman referred to members whose deaths had occurred during the year 1945, mentioning particularly Mr. Francis Samuelson, who was President in 1922-24, and a friend and colleague of his on the Board of Dorman Long; Dr. Vladislav Sykora, an Honorary Vice-President; and also another old friend, Mr. Harold E. Wright, the Bessemer Medallist of last year.

Welcome to Members and Visitors

The President extended a cordial welcome to all attending the meeting and referred especially to foreign and overseas members present, citing H. E. the Minister of Luxemburg, Dr. Andrew Clasen; Dr. George B. Waterhouse from U.S.A.; Mr. Howard Biers from Canada; a number of visitors from the Broken Hill Proprietary Company of Australia; Senor Ramon Quijano and other Spanish friends; an old friend in Dr. Durrer of Switzerland; a few French, Belgian and Dutch friends, including M. Bastien from France and M. Zimmer from Belgium; and a strong delegation from Sweden, where the Fernkontoret will, next year, celebrate the 200th anniversary of its foundation.

Report of Council

In presenting the Report of Council for 1945 the President said there has been an increase of 10% in the number of members of the Institute, which at the end of last year was 3,356. To-day there are about 3,700 members. This is a far larger figure than was contemplated before the war, and is good evidence that the Institute is doing work which is needed.

The chief event during the year has been the arrangements which have been made for affiliation with local societies and for collaboration with the British Iron and Steel Research Association. With regard to research, excellent arrangements have been made for collaboration with the British Iron and Steel Research Association. They are going to take over the Joint Research Committees, and the Institute is going to organise library and information departments for both bodies, and will print and publish their reports and papers. I hope that we shall be able to do many things jointly, such as arranging special meetings for sections of the industry, and so on. I think that we can help them also in their foreign relations.

In accordance with these arrangements, the Steel Castings Research Committee was dissolved at the end of the year, and the work taken over by new Committees operating under the Research Association. The Ingot Committee is to continue, but has been transferred to the Research Association. The Alloy Steels and Corrosion Committee will be transferred later.

Reference has been made already in this journal to the generous offer which Dr. Griffiths and the Mond Nickel Company made a few weeks ago, to present £50,000 for Fellowships in Metallurgy. This Institute and the other institutions to whom jointly the offer was made have accepted it with gratitude and enthusiasm. The President considered it a very good proposal, which will do a great deal in helping and encouraging young men of ability to become metallurgists. An announcement about the awards will be made as soon as arrangements have been completed, and it is hoped that this will be in time to make it possible for the first Fellowships to be given this summer.

Award of Bessemer Gold Medal for 1946

In presenting the Bessemer Gold Medal for 1946 to Mr. J. S. Hollings, C.B.E., the President said they first met in 1905 at a place called Brymbo. Mr. Dorman was a member of a small party from the Port Clarence Works of Dorman Longs who went to Chester seeking information on active mixers, from there they went to Brymbo where they met Mr. J. H. Darby. Mr. Hollings was fortunate in having, in his younger days, contact with such a great pioneer as Mr. Darby.

Later Mr. Hollings became interested in coke ovens and by-product plants—this was in their earlier days—and supervised the erection of plants in various parts of the country. He later became Managing Director of Brymbo, and when they were taken over by Baldwins he joined the Board of that Company and took a great interest in the management of their Port Talbot works. He then built the Cardiff works of Guest Keen Baldwins, which were amongst the finest in the country, and which were completed in 1936. Among his many activities was the supervision of the building of the South African Iron and Steel Corporation works in Pretoria.

In expressing his appreciation at the honour conferred upon him, Mr. Hollings outlined some of his experiences and his references to his experiments in blending coal for coke ovens, in the early days of their use in South Wales, were received with great interest. He acknowledged his indebtedness to many pioneers under whom he served and to the staff under him. In his concluding remarks he thought this Institute was inclined to attach, and quite rightly, great importance to technical achieve-

ments ; but, looking to the future, he thought that one of the most important ways in which to improve practice and output is by getting closer to the men.

Presentation of Williams' Prizes

The President then presented the two Williams' Prizes awarded for 1945, one to Dr. R. Jackson, for his paper on "The Application of Radiography to the Improvement of Foundry Technique," and the other to Mr. T. F. Pearson for his paper on "The Improvement of the Citric-Acid Solubility of Basic Open-Hearth Slags Containing Fluorspar."

Formation of an Iron and Steel Engineering Group

Arising out of a meeting of the Council, held in March, Mr. Headam-Morley (Secretary) reported its decision to set up an Iron and Steel Engineering Group of members of the Iron and Steel Institute to carry out the activities and functions of the Institute for engineers engaged in the iron and steel industry and in the design and manufacture of plant for the industry. As the head of the Group, an Engineering Committee has been set up under the Council. It will organise discussions and conferences, both centrally and locally, on subjects of interest to members of the Group. The Institute will be issuing a circular on the subject.

Changes on the Council

New Honorary Vice-Presidents : Mr. Fred Clements, Mr. E. J. Fox, and Sir William Larke, K.B.E.

New Vice-Presidents : Mr. W. J. Dasson and Mr. G. H. Latham.

New Members of Council : Sir Arthur Matthews, Mr. C. R. Wheeler, Mr. D. F. Campbell, and Dr. J. W. Jenkin.

New Honorary Members of Council : Sir Charles Goodeve and Sir John Duncanson.

In addition, the following Presidents of other societies have become Honorary Members of Council during their periods of office : Colonel P. G. J. Gueterbock, succeeding Dr. W. T. Griffiths (Institute of Metals) ; Mr. J. H. Patchett, following Mr. L. Wright (Cleveland Institution of Engineers) ; Mr. H. Bull, succeeding Mr. A. A. Munro (Sheffield Metallurgical Association) ; Mr. Ambrose Firth, succeeding Mr. F. Wardrobe (Sheffield Society of Engineers and Metallurgists) ; and Wing-Commander J. B. R. Brooke, succeeding Mr. C. R. J. Behrendt (Lincolnshire Iron and Steel Institute).

Induction of New President

After expressing his appreciation for the unfailing help he had received during his two years of office, Mr. Dorman, in handing over the Presidency to Dr. C. H. Desch, referred to him as a great scientist whom we have all known for many years and whose great work we all appreciate. Dr. Desch takes over the Presidency at a very important time and Mr. Dorman felt that the Institute was fortunate indeed to have induced him to undertake this office at this time. Continuing, he said, our relationship with the Research Association, thanks to Sir Charles Goodeve, promises very well, and we could not have a better man than Dr. Desch to improve those relations. I hand over the Presidency to him with great pleasure and great confidence and wish him a happy and successful term of office. Mr. Dorman then left the Chair, which was taken by the incoming President, Dr. C. H. Desch, F.R.S.

Presidential Address

In expressing his appreciation of the honour conferred upon him by electing him President of the Institute, Dr. Desch took the opportunity to thank Mr. Dorman for his many kind references to him when inducting him to the Chair. He then delivered an address on "Science and the Steel Industry," abstracts from which are given elsewhere in this issue.

Technical Sessions

The remainder of the morning session of the first day was taken up by the presentation of three papers on fuel economy in iron and steel works, on which a joint discussion took place during the afternoon session, namely : "Fuel Problems in the Swedish Iron and Steel Industry," by M. Tigerochiold ; "Problems in Fuel Efficiency," by C. Hulse and R. J. Sarjant ; and "Fuel Utilisation in Iron and Steel Works," by N. H. Turner and F. A. Gray.

Fuel Problems in the Iron and Steel Industry

At one time there were no fuel problems in this country; indeed in the eighteenth century we prided ourselves that adequate fuel and ore resources, adjacent to each other, were available for the economical production of iron and steel, and the fact that transport offered no real difficulties contributed to Britain building up a strong iron and steel industry. In those early days these raw materials were so cheap that little or no attention was given to conserving them or to their efficient use. To-day, the high cost of these materials has imposed problems which must be solved. The problems are not limited to this country ; indeed, it is only in relatively recent years that they have become acute here, whereas in many countries on the Continent the problems have existed since coke and coal were introduced for the production of iron and steel.

Formerly, for instance, as pointed out by Dr. Tigerochiold, the conditions for a Swedish iron and steel industry were extremely good, when charcoal and wood were the only fuels used. But as soon as coke was used more frequently as blast furnace fuel, the dominating position Sweden held in the world production of iron and steel ended. Sweden has, and always will have, great difficulties in competing with the large iron and steel producing countries of the world in the manufacture of commercial steel. One of the chief reasons is that there are no coal resources in Sweden worth mentioning.

Sweden's greatest resources in heat units are her extensive layers of bituminous oil-bearing shales. The peat moors, which form the next largest resource of fuel in Sweden, form a good reserve in war-time conditions. Last year the production of peat was raised to 1,250,000 tons, which corresponds to about 600,000 tons of coal. On the other hand, Sweden has a great advantage in her relatively large resources of water-power, the total potential hydro-electric power resources have been estimated at 36,000,000,000 kwh.

Before the war Sweden's normal import of coal and coke was 6,000,000 and 1,250,000 tons respectively ; the consumption of coal in her iron and steel industry reached about 600,000 tons in 1939. The State Commission for fuel supply during the war granted the iron and steel industry the following percentages of its normal consumption of coal :—

1st July, 1940—30th June, 1941	67%
1st July, 1941—30th June, 1944	30%
1st July, 1944—31st Dec., 1944	27%
1st Jan., 1945—30th June 1945	15%
1st July, 1945	7·5%

By the autumn of 1945 the situation had become most difficult, and straw (from rye, oats, and wheat) was introduced as a fuel in the iron and steel works. At one plant as much as 20% of the total fuel used consisted of pressed-straw bales, and an old blast furnace was rebuilt as a gas producer, using this material as fuel; this producer is operated with hot blast, and slag is tapped off in the molten state. One open-hearth furnace and several reheating furnaces are still heated with gas from this source.

At the time of writing (January 1946), Dr. Tigerochiöld states that the ration is still at the low level of 7·5% of the normal consumption, but it is hoped soon to procure more coal from abroad, including Britain.

It will be seen, therefore, that difficult as the fuel problems undoubtedly are in Britain they are not by any means so acute as in Sweden. Nevertheless, in this country fuel is to-day the major factor in the cost of production of finished steel, and fuel efficiency is a primary objective in steel plants. On this subject Mr. Hulse and Dr. Sarjant discussed problems relating to works where processes may be specialised; they consider the subject in relation to the bearing of fuel selection on efficiency, developments in furnace design and construction, methods of fuel saving in individual works, education, and research.

The works with which these authors are associated had for many years utilised a method of evaluating coals for industrial uses on a thermal basis, in which the ascertained calorific value on a basis of unit cost was adjusted for various operational factors; the result was that an "industrial value" of the fuel was determined. In the case of coal these factors had reference to ash content, clinkering characteristics of ash, and swelling character, while in the case of coke much importance was attached to the significance of the drop test, which had been found to give the best criterion of a hot-melting coke for cupola practice. In recent years, however, the problem has been to apply a much wider range of fuels (usually of an inferior character) to uses to which a particular selected fuel had previously been applied. How far it is desirable in the national interest and on technical grounds to revert to a free selection of suitable fuel is one which might well be given consideration.

Coal, pulverised fuel, coke, gaseous fuels, including coke producer gas, and liquid fuels are discussed in relation to their efficient combustion, but particular attention is directed to problems relating to plant design and the method of heat transference to the medium being heated; and to those mainly associated either with organisation or with technique. In this last section special prominence is given to the need for plant surveys with suitable instruments and for the necessary organisation and education to ensure the application of existing knowledge among the many, rather than to rely on spectacular advances by a few. Finally, some of the wider problems of research involved are briefly considered from the angle of suggestion.

Mr. Hulse and Dr. Sarjant point out that the general question of fuel research is, at the moment, one of some complication, and the need for co-ordination of the many sided approaches to the problem is apparent. In addition to the problems they discuss they append the following list of further suggested lines of research.

1. Is powdered coal to be a fuel of the future, or will the development of the mechanical stoker entirely supplant this medium?

If the use of powdered coal in metallurgical practice is to be further developed the following factors will require attention:—

(i) The laws of flow of mixtures of pulverized coal and air, in particular with regard to the influence of the fineness of division and the character of the coal.

(ii) Influence of flow velocity on the deposition of dust, and its bearing on the technique applied.

2. Designs of gas burners in use are legion. Can some common specifications be devised which characterise the essential features of burner design for specific uses.

3. An investigation is required of the causes of stratification and irregularities of flow of hot gases in furnace chambers and large ducts, and the derivation of the laws of flow and pressure drop in such conditions; the subject has particular reference to forced circulation.

4. What is the specification of a satisfactory valve or damper and how is that specification influenced by the temperature range involved? A specific case is that of the valve required for controlling the flow of tarry gas.

5. In furnace hearths, what is the ideal thickness for specific uses, and what is the ideal method of construction? How should bogie hearths be sealed to prevent air leakage? Can better means than at present exist be found for turning over ingots, blooms, and billets in the soaking zone of reheating furnaces?

6. A systematic study of the outstanding problems relating to the use of steam in iron and steel works practice is needed.

7. The use of the heat pump already referred to in the present paper has possibilities in connection with the recovery of waste heat.

8. Other requirements are:—

(i) Simple coal meters applicable to band and bucket conveyors and to chutes.

(ii) A heat flux-meter not involving the use of water.

(iii) A sensitive air-meter applicable to natural-draught furnaces, for use at the air intake.

(iv) A means to measure the stresses encountered in furnace crowns.

Further Problems in Fuel Utilisation

Consideration of some problems met with in current fuel utilisation practice at integrated and non-integrated iron and steel works is given by Messrs. N. H. Turner and F. A. Gray. These problems are chiefly concerned with blast furnace gas production, cleaning and distribution. To make existing plants as efficient as possible they point out that it is necessary:—

(*a*) To utilise fully the by-product gases;

(*b*) to prevent the loss of latent or usable heat existing in the material produced, after completion of the melting or heating process;

(*c*) to cause the necessary heat transfer from the fuel into the material being processed to take place with as high a degree of thermal efficiency as possible, and to use power in the most economical manner.

Integrated iron and steel plants represent one step towards the fulfilment of the first two conditions, but much has still to be done before the large amount of high-grade heat going to waste to-day is recovered: for instance, that lost with the blast-furnace slags, open-hearth slags, coke at the ovens, or from ingots as cast, and steel as rolled.

The points mentioned under (*c*) are receiving constant attention. The question of a decrease in the amount of low-grade heat going to waste with the flue gases, with

cooling water, and by radiation from the furnace shell must remain in the forefront. Some improvements have already been achieved by (i) use of better refractories, coupled with more efficient thermal insulation, (ii) extensive application of artificial draught (permitting more up-to-date means of waste-heat recuperation), (iii) fuller utilisation of furnace capacity, &c. Further improvements may also be expected from partial replacement of the combustion air by oxygen, made possible by the reduced cost of production of the latter.

After discussing fuel utilisation problems the authors describe the progress achieved in all the main works of The United Steel Companies since 1930, when fuel departments were started to give specialised attention to the important subject of fuel economy and gave an outline of what had been achieved. An interesting appendix to this paper gives a brief description of fuel-using plants.

Considerable discussion followed the presentation of these papers. At times it was of a lively character and always informative and interesting. It is not possible to deal with it here because of lack of space, but some indication of the interest displayed on the subject is given when it is stated that the following contributed: Mr. J. B. M. Mason, Chief Technical Officer, Ministry of Fuel and Power; Dr. G. Doxey, Stewarts and Lloyds, Ltd., Corby; Mr. H. G. Armstrong, Thomas Firth and John Brown, Ltd.; Mr. W. M. Thring, British Coal Utilisation Research Association; Mr. Frank Kennedy, Dorman Long, Ltd.; Mr. G. N. Young, Richard Thomas and Baldwins, Ebbw Vale; Mr. T. F. Pearson, Colvilles, Ltd., Clydebridge Steel Works; and Dr. R. Durrer, Switzerland.

The Detection of Cracks in Steel by Means of Supersonic Waves

The next paper to be presented at the meeting was on the above subject and was submitted by the Hair-Line Crack Sub-Committee of the Alloy Steels Research Committee. This paper, by Dr. Desch, Mr. D. O. Sproule and Mr. W. J. Dawson, is in three sections: The first reviewing previous methods of detecting flaws in steel by means of sound waves, especially high-frequency, and including a short account of a method of measuring damping of oscillations of high frequency and very small amplitude. The second section describes apparatus employing piezo-electric quartz transmitters for producing intermittent pulses of supersonic waves and receiving them on similar quartz crystals for reflection, the reflected waves being electrically amplified and indicated on a cathode-ray oscilloscope. The conditions for obtaining sharp indications are discussed, as well as the effects of the degree of finish of the metallic surfaces under examination. In the third section are given the results of applying the new method in works practice, including large masses, billets, plates, castings and welds. The conditions necessary for the satisfactory use of the apparatus for practical testing are discussed. It is maintained that supersonic testing should be regarded primarily as a new instrument of investigation, giving information which cannot at present be obtained by more usual methods.

Section 1 and, in the absence of Mr. Dawson owing to illness, section 3 were presented by Dr. Desch, while section 2, in the absence of Mr. Sproule on the Continent, was presented by Mr. A. C. Rankin.

Discussion

Considerable discussion resulted but only brief reference can be made here to some of the remarks. Mr. L. Rotherham thought that the damping capacity measurements of the kind that Dr. Frommer started are more selective if they are properly interpreted than are the supersonic observations. The contributions to damping of elastic phenomena and the effects of heat treatment, plastic phenomena and flaws can be distinguished to an extent; but there is no possibility of doing that with the supersonic apparatus, and in fact we do not measure the total scattering of energy but only that energy which is scattered in a particular direction.

Mr. H. Nicholson said that several applications of this method have been made to forgings of 10 tons and over, which are in the large category, and these have been made since the paper was written. Quite definite responses have been obtained from hair-line cracks, from large inclusions and so on. He felt that Dr. Desch has quite correctly emphasised the limitations of the supersonic instrument as an all-purpose instrument of inspection.

Dr. P. G. Bastien said the method had not been used in France and thought that, in the case of very large components, such as rotors for turbo-alternators, the simultaneous propagation of longitudinal and transverse vibrations ought to be easy, and asked if it was always possible, in such cases, to obtain a satisfactory elimination of the transverse waves. The question whether the supersonic flow detector was applicable to the problems of the aluminium industry was put by Mr. N. S. Brommelle; he referred particularly to the detection of pinholing in aluminium blocks, castings, etc. This question was taken up by Mr. E. G. Stanford, who explained work which had been carried out at Aluminium Laboratories, Banbury. In the application of the flaw detector to the aluminium industry, he thought a nearer approach had been made than in the case of the steel industry. Cracking is experienced at the root of the T in T-sections in aluminium and as yet we have not been able to apply the supersonic method to detect this type of defect; it would be a great help if the crack detector could be used for searching the first half-inch. In his closing remarks Mr. Stanford referred to the application of the method to the examination of steel rolls which give trouble through cracking.

Mr. D. A. Oliver paid a tribute to the authors of this co-operative work, which he regarded as a valuable preliminary survey. After giving his explanation of one of the illustrations in the paper, he mentioned an important point about this method of testing. He has worked on this with Mr. Harris, who is part author of Section 3, but at the moment success has been limited to simple forms of test pieces. Forged discs for gas turbines and jet engines have been examined to determine the soundness of the centre of the forging. Two faces of a 5-in. thick disc were machined and many thousands of forgings have been explored. A measure of axial looseness or slight porosity was found, and the energy absorption of the very slight looseness in the structure was in a broad kind of way capable of calibration.

Dr. M. T. N. Pourbaix, of the Association des Industries de Belgique, referred to work carried out in Belgium during the war on the development of a method for supersonic testing. The main part of the work was done during enemy occupation, and had to be preserved from

German curiosity. The conditions in which the work was done were therefore difficult and the results have not been on the scale recorded in the paper before the members. He then gave a brief description of the apparatus used.

Mr. W. R. Yates desired to clarify points raised by workers on the aluminium side. With regard to the examination of round bars and curved surfaces, a technique has been developed by which we mould Perspex and press it on to the surface. Usually the bar has been machined. The coupling medium is shale oil. We require oil between the surface and the Perspex, and again between the Perspex and the round bar.

Mr. Stanford spoke about castings, but much of Mr. Yates' work has been on forged material, and the type of defects on which work has been done is the hair-line crack or segregation. The hair-line crack is only found by examination perpendicular to the plane of the crack, and it is necessary to machine and grind the surface to make a reliable examination, because the examinations in the works on rolled material require filters.

Mr. W. C. Hesselwood said the objective of the apparatus was its application in determining the presence of hair-line cracks and that objective has been achieved. The two cases in which there has been a lack of success with the equipment are: first, in the examination of cast steel, including ingots, where it has not been very successful in finding some of the things that we want to know about cast steel; the energy seems to be dispersed by the inherent looseness of the structure, and, secondly, by reason of the known limitation in not detecting defects less than about 0·5 in. from the surface. Those are the two fields which could usefully be explored.

Mr. A. C. Rankin discussed some points raised by Mr. Yates and went on to give some experiences in testing. As makers of the instrument, he said, we have tried to co-operate with the industry, and we always want to understand what it is that is required. The question of cast material has been raised. I have had experience with cast material, and it seems that it is not so much a limitation of the principles of supersonic testing as a limitation of the metallurgical requirements. In any cast material we very rarely find complete homogeneity, and therefore we have to learn how to ignore things which can be tolerated and how to find others which cannot be tolerated. Often it is like looking for a tree in the middle of a wood, and as such it brings out the fact that we cannot violate physical principles in order to achieve our results. The work on castings, of course, is still going on.

Overheating and Burning Steel

Although considerable discussion followed the presentation of previous papers at this meeting they were somewhat dwarfed by the extent of the discussion of a series of papers which could be regarded as a symposium on the overheating and burning of steels. The series comprised five papers, viz.: "Some Aspects of the Overheating of Steel Drop-Forgings," by H. J. Merchant; "The Overheating and Burning of Steel," by C. Preece, A. Hartley, S. E. Mayer, and J. Nutting; "Overheating and Burning of Nickel-Chromium-Molybdenum Steel," by W. E. Goodrich; "The Effect of Oxygen on the Trothermal Transformations of Steel, and a Suggested Test for Burning," by F. C. Thompson and L. R. Stanton; and "Some Experiments on Overheating," by J. Woolman and H. W. Kirby. These papers were presented in summary form by Dr. J. W. Jenkin.

In the first paper of the series Mr. Merchant, of Sydney, Australia, discusses the effects of overheating on the serviceability of steel drop-forgings, particularly in relation to their use in aero-engine construction. Describes the principal causes of, and factors influencing, overheating, and attempts to differentiate between overheated steel, severely overheated steel, and burnt steel. The greater part of the paper is devoted to a description of the methods used to detect overheating in alloy steel, namely, examination of the surface and of the fracture, metallographic examination, and mechanical testing. He describes work carried out with a view to studying obscure aspects of the subject, together with an attempt to establish fracture-test standards. He also gives an account of methods of preventing overheating and of reclaiming overheated steel. Finally, some notes are given on the occurrence of overheating in American steels, and some suggestions regarding directions which might be taken by future research on this subject.

The paper on the subject by Mr. Preece and his colleagues is published by authority of the Alloy Steels Research Committee, they deal with the overheating properties of a wide variety of steels. Temperatures of overheating have been determined on the basis of the fracture and etch tests. According to this work there would appear to be no clear relationship between the overheating temperature and the normal specified analysis of the steel, or its oxygen and nitrogen contents. Open-hearth steels have generally a higher overheating temperature than electric steels. Correlation has been observed between the inclusion content of a steel and its overheating temperature. Furnace conditions, such as composition of the atmosphere, soaking time, and the rate of cooling, have been studied in relation to overheating. From this, the possibility of a slow cooling treatment as an effective method of restoring overheated steels has been indicated. The effect of overheating upon the tensile and Izod properties has also been examined.

Results obtained in this investigation, although not complete, provide further information on the mechanism of overheating.

Sometimes mechanical-test results from forgings of carbon and alloy steels satisfactorily fulfil test requirements although the fractured test-piece discloses small areas which have been regarded as evidence that the steel has been "burnt." Another view is that this feature is indicative of overheating before forging or other hot manipulative operations. Evidence has accumulated, however, which shows that a repetition of the normal oil-hardening and tempering treatment or slow cooling from customary forging temperatures, appreciably reduces, and in many cases entirely eliminates, this abnormal type of fracture. It seems logical to conclude, therefore, that had the steel really been burnt, this apparent recovery could not have taken place, and the investigation described by Mr. Goodrich was carried out to ascertain why certain heat-treatment operations apparently produce greater strength in the interior of the crystals than at their boundaries.

In this investigation a series of experiments were therefore conducted on sections machined from a nickel-chromium-molybdenum-vanadium steel forging, the sections being heated to initial temperatures varying between 1250° and 1400° C. and subjected to various cooling treatments, in some cases followed by a further

standard oil-hardening and tempering operation. Afterwards, the specimens were fractured and their fractures and metallographic structures, in the various heat-treated conditions are described.

It has been shown that a repetition of normal oil-hardening and tempering treatments, or slow cooling from overheating temperatures, can appreciably reduce, and in many cases entirely eliminate, the abnormal granular type of fracture. All the evidence obtained indicated that it was necessary to cool fairly rapidly through the upper critical range to create conditions favourable for the formation of the granular facets, and even then tempering temperatures exceeding approximately 400° C. were necessary to produce the relative strengths of the crystals and crystal boundaries required for their formation.

Even at overheating temperatures of the order of 1400° C., no incipient fusion was detected at the grain boundaries or within the grains, though there were signs of a metallographic change apparently taking place in the solid state at the grain boundaries and also originating from non-metallic nuclei within the grains.

Prof. Thompson and Dr. Stanton have suggested that an explanation of the phenomenon of "abnormality" may possibly be found in absorbed oxygen moving, directly or indirectly, the S curve of the steel to the left, thus rendering the material more reactive. At the time when the hypothesis was propounded, there was no evidence by which its truth could be confirmed. The present paper by these authors describes an attempt to provide such evidence by a series of experiments which consisted of burning a small area only of a number of specimens of a steel known to behave normally in its original condition. It has thus been possible to compare the microstructures of the burnt and unburnt areas of the same specimen.

The results show that certain steels are rendered more reactive by burning, and this suggests a displacement of the inherent S curve; the nature of the final product of transformation indicates that this displacement is in a vertical direction, which in effect acts as a shift to the left.

The deduction is made that this behaviour is due to the introduction of oxygen during burning, which probably acts indirectly. The effect is absent in other steels of similar composition, as determined by ordinary method of analysis, and in general it is found to be too erratic to offer a universal test for burning.

The work reported in the paper by Mr. Woolman and Mr. Kirby, was initiated by the finding of overheating effects, namely faceted fractures, in certain forgings made from 3% nickel-chromium-molybdenum, 3% nickel-chromium-molybdenum-vanadium, and 2/2 nickel-chromium steels. Preliminary work consisted in evaluating the overheating temperatures for the different steels, attempts to recover overheated material, and the determination of factors affecting the response of the steel to exposure at high temperatures. As a result of these preliminary experiments further work has been carried out, particularly to ascertain what factors in the steel-making conditions have an influence on the over-heating temperature, since considerable confirmatory evidence had been obtained that the overheating temperature tends to be different in steels made by different processes.

Some evidence is submitted in support of a hypothesis that the overheating phenomenon indicated by faceted fractures is a precipitation effect and is not the result of external gas atmospheres. It is considered that the precipitate is already present in the steel as cast, and the effect of heating to a high temperature is to redissolve it. Subsequent cooling, if at a suitable rate, results in a precipitate forming at the existing austenite boundaries which then persists as a network. This is reflected in the final fracture test by interruptions in the path of the crack, giving rise to the faceted type of fracture.

The indications are that the rate of cooling from the overheating temperature is an important factor in producing faceted fractures. The method of steelmaking and the addition of aluminium and other killing agents also have an influence on the minimum overheating temperature, although the reasons for both effects are not yet clear.

The vacuum-melting experiments have also shown that remelting a material having a very high minimum overheating temperature can substantially reduce that temperature, although the variables due to changes in composition introduce complexities.

Besides oxygen, the sulphur contents appear to play an important rôle in the phenomenon.

Discussion

After comments and discussions by some of the authors of the various papers, Dr. H. Sutton, the first of a large number of members who contributed to the discussion, said these papers refer to a trouble which, like hair-line cracking, happens to be closely associated with those periods in the world's history during which, as mentioned by Mr. Merchant in his paper, the production of forgings is greatly accelerated. The present time seems to be a very opportune one for careful consideration of the phenomenon. In this connection we are greatly helped by this very interesting set of papers, which provide a vast amount of information. He had much more to say about the subject as also had Mr. Hind, Mr. Frith (a contribution read in his absence), Prof. G. Wesley Austin, Dr. P. G. Bastien, Mr. E. H. Bucknall, Mr. J. D. Latta, Dr. H. O. Neill, Prof. Waterhouse, Mr. H. A. Whiteley, Mr. W. E. Cooper (a contribution read in his absence), Dr. Wrazej and the President, Dr. Desch, who was in the Chair.

Correspondence

Aluminium and the Building Programme

The Editor, METALLURGIA.

Dear Sir,

We were interested in the article by Mr. Mortimer on the above subject in your February issue and would mention that this Association is forming a Publicity Committee in order to avoid any misconception as to the extent of our members' responsibility such as might arise from the article.

It must be known that our members produce castings, mainly for firms who incorporate aluminium castings in their legitimate range of manufactured articles. Builders' merchants who want castings on their shelves, similar in nature to builders' iron castings, can generally have them by placing an order with their nearest aluminium founder. The builders' merchants will find that the aluminium foundry industry shows a lively interest in supplying castings direct, in large or small quantities. This includes many castings which have been produced in iron, such as rainwater goods, brackets, airbricks, etc. It must be appreciated, however, that this direct business is in

plain castings where the casting is a finished product ready for sale.

For manufactured products those firms specialising in this type of work could satisfy a growing demand by co-operating with the aluminium founders and thus using their technical knowledge and capacity to produce the castings required since aluminium founders sell castings, not finished products. Members have shown a lively interest in new uses for aluminium castings, but whilst there may be cases, here and there, where individual firms have been approached, as suggested in the article, there is no universal experience of such enquiries amongst the L.M.F.A. in general.

Sinks, draining boards and, for that matter, wash-basins were developed some months past, either as castings or as composite cast-wrought design, but it has been extremely difficult to obtain the blessing of the Ministry of Works and Building. Regarding windows, the present design of aluminium window is based on steel construction methods which is pre-eminently a job for extrusions. There is little doubt that if window specialists were to work with the aluminium founders to evolve a design specifically suitable for casting, particularly satisfactory results would be achieved.

This Association will be delighted to render all possible assistance on matters concerning castings. We agree with Mr. Mortimer that builders are entitled to obtain builders' castings by telephoning their merchants. If the merchants wish we can put them in touch with various members of this Association who will supply castings to place on their shelves.

Yours faithfully,
(Signed) A. H. STURDEE,
Chairman of the Light Metal Founders' Association.

25, Bennetts Hill,
Birmingham, 2.
April 30, 1946.

DR. R. GENDERS has recently relinquished the post of Superintendent, Technical Applications of Metals, Ministry of Supply, in order to take up private practice as a Consultant on Materials and Research. He has been retained as Metallurgical Adviser by the Ministry of Supply.

The Editor, METALLURGIA.

Dear Sir,

Mr. Sturdee makes some pleasant and constructive comments on my article on Aluminium and the Building Programme in your February issue. As former Chairman of the Aluminium Foundry Group, from which his live and practical Association grew, I can well visualise the intricacy of some of his present problems, and it was of course no part of my intention to add to his task. It is good to know that his Association is forming a Committee to deal with the sort of misconception referred to in the article, for there is undoubtedly need of such missionary work, and not only on the castings side.

I have read somewhere that numbers of Indians will quietly starve in the absence of rice, with ample supplies of wheat handy. They are used to rice and not used to wheat. Similarly, numbers of builders, and their merchants, are daily short of supplies in the materials they are used to, and few realise the potentialities of the light metals industry. A very large section of those concerned in some way with building think of that industry, if they think of it at all, in pre-war terms. One seldom meets one who has grasped the fact that aluminium has become a solid factor in our national life, like coal and iron. Not many of them read technical articles, and quite a few seem to read only one advertisement, their own, to see that they are getting their money's worth.

Some re-orientation of ideas is needed in the building trades, and one way of bringing that about is by arranging for some depot where both builders and their merchants can see and *handle* light alloy building components, and find out who makes them in quantity. The late Mr. Percy Pritchard, in his bluntly practical way, would probably have added that one lunch with the right people there would do more good than a dozen exhibitions and a hundred articles such as mine of February. These things I am more than content to leave to the Light Metal Founders' Association, knowing something of their reputation for practical co-operation during the war, and happy to learn that they are carrying that spirit in the problems of Peace.

Yours faithfully,
GEORGE MORTIMER.

The British Aluminium Co., Ltd.
May 13th, 1946.

Hatfield Memorial Lecture

THE Hall at the Institution of Civil Engineers was well filled with members of the Iron and Steel Institute and visitors to hear Dr. George B. Waterhouse, Professor Emeritus of the Massachusetts Institute of Technology, deliver the first Hatfield Memorial Lecture, on May 1, 1946, at 8-30 p.m. Dr. C. H. Desch, F.R.S., President of the Iron and Steel Institute, was in the Chair. In opening the proceedings Dr. Desch referred to the foundation of the memorial, stating that " under a deed dated August 22, 1944, the University of Sheffield agreed to be the trustees of the fund which was subscribed for the purpose of establishing a lecture on the subject of metallurgy or some other subject connected therewith as a memorial to the late Dr. William Herbert Hatfield, F.R.S., and as a mark of appreciation of his distinguished work in connection with research into the qualities and uses of metals and allied branches of science. The lectures are to be known as the Hatfield Memorial Lectures."

" We are very fortunate in having been able to secure, as the first lecturer, Dr. Waterhouse, who is actually a Sheffielder, and who attended the classes of the University of Sheffield at about the same time as Dr. Hatfield. After some time Dr. Waterhouse went to America, where, for a long time, he held the very important position of Professor of Metallurgy at the Massachusetts Institute of Technology, from which he retired only in December of last year. He has done very important work, especially during the war. I am very glad that on this occasion we are to have a lecture from one who was actually with Dr. Hatfield in his early days in Sheffield and who has since built up a reputation for himself across the Atlantic."

Dr. George B. Waterhouse regarded it as a great honour to give the first lecture and to be able in this way to pay tribute to a great and distinguished metallurgist in the field of iron and steel. He considered it very fitting that this first lecture should be held during the meeting of the Iron and Steel Institute, because Dr.

Hatfield was a loyal and devoted member of the Institute for over forty years.

He was a native of Sheffield. While working as a young man in a steel work's laboratory he attended evening classes at the Sheffield Technical College, where he studied under J. O. Arnold, A. McWilliam, F. Ibbotson and F. K. Knowles. These men had a great influence on him, as they had on all who attended their courses. He graduated and was awarded the highest honour, the Mappin Medal in 1902, when only twenty years old. For the next fourteen years he was connected with John Crowley and Co. Ltd., as metallurgist and manager and later director, and was greatly interested in steel castings, cast iron and malleable cast iron. He continued his scientific studies in connection with the College, which during this period became a part of the newly-created Sheffield University. In 1913 he received the degree of Doctor of Metallurgy. During this period appeared the first of his very large number of papers dealing with iron and steel.

In 1916 he was appointed Director of the Brown-Firth Research Laboratories in Sheffield, succeeding Mr. Harry Brearley, the discoverer of the cutlery type of stainless steel. This proved to be an ideal appointment, Hatfield found full scope for his interest and activities and continued as Director until his death in October, 1943. The two companies served by his research laboratories were merged in 1930 to form Thomas Firth and John Brown, Ltd., and he later became a member of the Board of Directors. He was also a director of one of the associated companies, the Firth-Vickers Stainless Steels, Ltd., and maintained very close contact with the other subsidiaries, and with the associated American Company, the Firth-Sterling Steel Co., of Pittsburgh, Pa.

During the period of 1916 until his death he published no less than 123 more papers. In 1928, he delivered the Campbell Memorial Lecture at the Tenth Annual Convention of the American Society for Steel Treating (now the American Society for Metals). His subject was the application of Science to the Steel Industry. It was amplified and published by the Society as a book of 154 pages.

Beginning with 1929 an increasing number of his papers dealt with steel ingots, with corrosion and with research as regards alloy steels. These were essentially reports on the work of important Committees in which Hatfield was interested, complete details of which are given in Special Report No. 29 of the Iron and Steel Institute, a book of 175 pages, published in 1943, and originally prepared by Hatfield, and various members who worked on individual sections.

In his concluding words Dr. Waterhouse tried to answer in part the question, what made Dr. Hatfield act as he did? I feel sure, he said, that among his ruling motives was a just and proper ambition to succeed in whatever task he undertook, and without any doubt I know one of his strongest motives was to carry out as far as he could the teachings of the Golden Rule, which are needed in engineering as in religion.

And so we see Hatfield developing as the years went on, so that when his great task presented itself he was ready. His interests and his influence covered his beloved country. No change of attitude or of motive was needed. Each demand found him ready and when his appointed time arrived he never flinched, but went to his grave, and to his reward, as any of the brave heroes of old.

Announcements

CONSEQUENT upon the growth of the demand for the well-known range of hiduminium alloys, branch offices have been opened at Manchester and Glasgow on May 1st, 1946, jointly by: High Duty Alloys Limited, Reynolds Tube Co., Ltd., and Reynolds Rolling Mills Ltd., each in charge of qualified Representatives.

Enquiries for, and technical advice on, the correct application of aluminium alloys generally will be welcomed from intending users resident in these areas.

The addresses of these offices are as follows:—

MANCHESTER:—
4, St. Ann's Square, Manchester, 2.
Telephone: BLAckfriars 4881.

GLASGOW:—
69, West Regent Street, Glasgow, C.2.

MESSRS. A. C. WICKMAN, LTD., Coventry, announce that as from May 1st, 1946, Mr. W. R. Bedford, at present Area Manager at Bristol, is being appointed Area Manager at Manchester, and that Mr. W. J. Bottomley is being appointed Area Manager at Bristol.

Mr. H. Eckersley, previously Area Manager at Manchester, has been appointed Manager of the newly formed Tungsten Carbide Development Division of the organisation with headquarters at Torrington Avenue, Coventry.

INTERNATIONAL ALLOYS, LTD., announce that their operations and Head Office have been transferred from Slough to their Aylesbury Factory and that their address is now: International Alloys, Ltd., Bicester Road, Aylesbury, Bucks. Telephone No.: Aylesbury 1010.

MESSRS. HADFIELDS, LTD., of Sheffield, announce the forthcoming retirement of Mr. W. A. Green. He joined the Company on February 1st, 1891, and for 45 years has represented them in Birmingham and the South Midlands, where his geniality, abundant industry and extensive knowledge have established him as one of the most popular and highly respected figures in the district.

Mr. Green's duties will be taken over by Mr. C. F. Jarratt. A metallurgist with long experience in the steel industry, Mr. Jarratt was, until recently, Area Progress Officer to the Admiralty Director of Armaments Supplies. He will move to Birmingham on May 8th.

THE Ministry of Supply announces that in addition to its purchases of virgin copper from Rhodesia, the Belgian Congo and Canada in the first half of 1946, it has also bought 30,000 tons of copper from Chile in the same period.

Johnson Matthey Industrial Exhibition

AN EXHIBITION of unusual interest is being held by Johnson, Matthey & Co., Ltd., at Dorland Hall, Lower Regent Street, London, S.W. 1, from June 13th to 26th inclusive.

This Exhibition has been arranged in order that the specialised products and services of the company, and their applications in an ever-widening range of industries, may be seen for the first time as a comprehensive whole. It will reveal many interesting and important advances made in the light of wartime experience.

Admission will be by Invitation Card only. Application for cards should be addressed to: The Exhibition Secretary, Johnson, Matthey & Co., Ltd., 73/83, Hatton Garden, London, E.C. 1.

MICROANALYSIS
CHEMICAL AND PHYSICAL METHODS
APPARATUS · METALLURGICAL APPLICATIONS · TECHNIQUE

RECENTLY we were privileged to listen to a—somewhat heated—argument concerning the value of short notes such as those which we include from time to time in this Section. In passing, we may add that the argument did not arise from a discussion of this Section. Like most arguments which can have two sides, no very definite conclusion was reached. But we were set thinking along lines which touched on our policy in so far as it approves the inclusion of these notes. For many years we have held the view, which has been decidedly strengthened by visits to a wide variety of laboratories, that there lie, locked up in the small areas bounded by the four walls of each laboratory, numerous devices and dodges, labour-saving or ingenious or both, which would be of enormous benefit to chemists if only they were widely known. How often have we acquired, through a purely chance visit, some pointer about which we have immediately felt ; "How obvious. Now why didn't we think of that ?" On enquiry, we find that the method or what-not has been in use for years. "We didn't think it worth publishing a scrap like that." Microchemistry, by its very nature, continually leads its devotees to such invention. And it is our belief that to bring before a wider audience of microchemists any useful hint that is brought to our notice is of benefit to a high percentage of that audience. One day, when paper shortage is less acute, we promise ourselves that we will try to prove this contention.

Microquantitative Analysis of Sodium and Potassium

By F. Burton

The determination of sodium and potassium rank amongst the more important methods of analytical chemistry since the two elements are present in such a wide variety of substances, ranging from silicate rocks and soils on the one hand, to biological fluids and waters on the other. For many years the determination of these metals was regarded as an exacting procedure and even to-day the determinations are not classed with the simpler methods of analytical chemistry, mainly because of the lack of simple insoluble salts which they form.

I. SODIUM

SOME 30 reagents have been used for the detection of potassium and about nine for the detection of sodium. In the latter figure all the double acetate reagents are regarded as a single type. Although this suggests that a wide choice of reagents is available, many of these tests still await quantitative application. Microscopic tests, where the elements are detected by the formation of characteristic crystalline form, are not included amongst the present survey, but it is of interest to note in this connection that Tichomarov and Cholmogorov[1] have used potassium lead copper nitrite as the weighing form in the determination of potassium on the macro scale. This compound has been used for many years in chemical microscopy for the identification of potassium, lead or copper.

Reagents which have been used for the determination of sodium on the micro scale are zinc uranyl acetate, magnesium uranyl acetate, manganese uranyl acetate, caesium bismuth nitrite—Ball's reagent, and potassium dihydrogen antimonate—Fremy's reagent ; but despite the fact that the triple acetate method was the latest to be applied quantitatively, it has received considerably more attention than any of the others.

1 Tichomarov and Cholmogorov, *Zav. Lab.*, 1938, **7**, 33.

Triple Acetate Methods

When sodium has been precipitated as a triple acetate, the determination may be completed in one of the following ways :—

(1) The precipitated triple acetate may be dried and weighed as such.
(2) The amount of precipitate can be measured by collecting in a graduated capillary tube under centrifugal force and reading the volume.
(3) The amount of sodium in the precipitate can be measured by means of a colorimetric procedure.
(4) A titrimetric method can be applied.
(5) An electrometric finish can be employed.

Gravimetric Methods

Although the very favourable conversion factor enables the assessment of comparatively small amounts

of sodium, the bulk of the literature is devoted to titrimetric and other procedures allowing the determination of even smaller quantities. On the micro scale the gravimetric procedure follows the macro procedure except that conventional micro technique and precautions are employed.

Titrimetric Methods

Titration with Potassium Dichromate. Kolthoff and Lingane[2] recommend the use of potassium dichromate for the volumetric determination of sodium, since the titrant can be kept indefinitely without appreciable change in strength. The end point with diphenylamine sulphonate indicator is easily detected if ferric iron is added to the tetravalent uranium solution.

The sodium is precipitated as sodium zinc uranyl acetate, the precipitate dissolved in dilute sulphuric acid and the hexavalent uranium reduced to the tetravalent state by the method of Lundell and Knowles. After the addition of ferric chloride, phosphoric acid and barium diphenylamine sulphonate, the solution is titrated with potassium dichromate solution to the appearance of the stable violet colour.

A similar titrimetric procedure using zinc uranyl acetate in conjunction with the dichromate finish has been advanced by Ball and Sadusk[3] and is recommended for use in the determination of sodium in blood serum.

Titration with Potassium Permanganate. The method of Gall and Heinig[4] in which the solution of sodium zinc uranyl acetate in sulphuric acid is filtered through a layer of electrolytic cadmium, and the reduced uranium solution titrated with potassium permanganate, has been modified to the micro scale by Chen.[5] The sample containing 0·04 to 0·2 mg. of sodium is treated with ethyl alcohol and zinc uranyl acetate. The precipitated triple salt is dissolved in sulphuric acid and reduction effected by means of a cadmium stick. The reduced solution is finally titrated with dilute potassium permanganate solution.

Raszeja[6] has developed a micro volumetric method for the determination of sodium in blood. Sodium is precipitated with magnesium uranyl acetate after the destruction of organic material and removal of phosphates. Raszeja maintains that the precipitate, when dried at 105° C., loses but one molecule of water of crystallisation, not nine as earlier workers stated.* The precipitate may either be weighed and the sodium determined gravimetrically, or preferably it may be dissolved in water and sulphuric acid, the uranium reduced with zinc amalgam in an inert atmosphere, and the quadrivalent uranium re-oxidised by titration with standardised potassium permanganate solution. The method is reported to produce results with an error of less than 0·5 per cent. of the total sodium.

An examination of the method of determining sodium in water by means of zinc uranyl acetate has been made by Wiggins and Wood.[7] The precipitated triple salt was found to be appreciably soluble in water to the extent of 5 to 6 per cent. at 15° C., but the addition of excess reagent was found to reduce the solubility to a negligible amount. These authors have developed an accurate and convenient volumetric method by which sodium can be determined in concentrations of sodium chloride corresponding to 2·5—40 gm. per litre.

Titration with Sodium Hydroxide. Clark and his co-workers[8] describe the determination of chlorine, sodium and potassium in ore sample. Chlorine is determined by absorbing in potassium hydroxide the hydrogen chloride volatilised by treatment with sulphuric acid. Sodium and potassium are determined in the sulphuric acid digest. The former is precipitated as sodium zinc uranyl acetate which is dissolved in water and titrated with sodium hydroxide using alcoholic phenolphthalein as indicator.

Weinbach[9] recommends titration of the solution of sodium zinc uranyl acetate with 0·02 N sodium hydroxide when the following equation is approximately true.

$$(UO_2)_3\ ZnNa(CH_3COO)_9\ 6H_2O + 8NaOH = 3UO_2(OH)_2 + Zn(OH)_2 + 9CH_3COONa + 6H_2O$$

The alkalimetric method has been thoroughly investigated by Morton[10] who found that the end points of titrations carried out according to the method of Weinbach are transient and difficult to determine. He found, however, that when stronger solutions of the triple salt are titrated with 0·1 N sodium hydroxide the stoichiometric relationship is slightly different and the reaction is more accurately represented by the equation :—

$$(UO_2)_3\ ZnNa(CH_3COO)_9\ 6H_2O + 9NaOH = NaHUO_4 + 2UO_2(OH)_2 + Zn(OH)_2 + 9CH_3COONa + 7H_2O$$

Titration with Ceric Sulphate. In the drop scale procedure of Holmes and Kirk[11] sodium zinc uranyl salt is reduced with cadmium and ceric sulphate is used as the titrant. An accuracy of 1% using 0·13 to 4·13 micrograms is claimed.

Colorimetric Methods

Hoffman and Osgood[12] have described a method in which measurement is made of the yellow colour of the sodium zinc uranyl acetate. The precipitate is dissolved up, phosphates being simultaneously removed as insoluble uranyl phosphates which form as a gelatinous precipitate. Ammonium thiocyanate is added to stabilise the colour against temperature change. The method is stated to be subject to an error of ± 1% or even less.

Potassium Ferrocyanide. A number of the colorimetric and photoelectric methods in general use depend upon the colour developed with uranium by potassium ferrocyanide. This reaction has been used largely in macro methods but it has also been applied on the micro scale by Marenzi and Gerschman[13] for the determination of sodium in serum and plasma. The solution of the trichloracetic acid filtrate of the serum is precipitated with zinc uranyl acetate, washed, dissolved in acetic acid, treated with potassium ferrocyanide and compared colorimetrically.

Mulwani[14] recommends the potassium ferrocyanide colorimetric finish after precipitation of the sodium as sodium zinc uranyl acetate. Determination of 0·0016—0·16mg. is possible and it is reported that the presence

* Much controversy has raged about the number of molecules of water of crystallisation attached to the triple acetates. For further information see Caley and Baker, *Ind. Eng. Chem., An. Ed.*, **11**, 604, 1939.

2 Kolthoff and Lingane, *J.A.C.S.*, 1933, **55**, 1871.
3 Ball, E. G., and Sadusk, J. F., *J. Biol. Chem.*, 1936, **113**, 661.
4 Gall, H., and Heinig, K. H., *Z.anorg. Chem.*, 1931, **202**, 154.
5 Chen, G., *J. Lab. Clin. Med.*, 1936, **21**, 1198.
6 Raszeja, S., *Bull. Soc. Chim. Biol.*, 1935, **17**, 817.
7 Wiggins, W. R., and Wood, C. B., *J. Pet. Tech.*, 1935, **21**, No. 136, 105.
8 Clark, W. G., Levitan, N. I., Gleason, D. F., and Greenberg, *J. Biol. Chem.*, 1942, **145**, 85.
9 Weinbach, A. P., *J. Biol. Chem.*, 1935, **110**, 95.
10 Morton, F., *Analyst*, 1945, **70**, 247.
11 Holmes, B., and Kirk, P. L., *J. Biol. Chem.*, 1936, **116**, 377.
12 Hoffman, W. S., and Osgood, B., *J. Biol. Chem.*, 1938, **124**, 347.
13 Marenzi, A. D., and Gerschman, R., *Compt. rend. Soc. Biol.*, 1933, **114**, 1212.
14 Mulwani, B. T., *J. Univ. Bombay*, 1940, **8**, [11], 128.

of calcium, magnesium, iron, aluminium and manganese is without effect although potassium must be removed if the ratio of potassium to sodium exceeds 4 : 1.

The same method has also been used, with slight modification, by McCance and Shipp[15] and also by Salit[16] for the determination of the element in biological fluids.

Sulfosalicylic Acid and Sodium Acetate.—The colour developed by sodium zinc uranyl acetate on treatment with sulfosalicylic acid and sodium acetate was investigated by Darnall and Walker.[17] Briefly the method consists in precipitation of sodium zinc uranyl acetate from alcoholic solution, removal of phosphate as in the method of Hoffman and Osgood[12] and photoelectric measurement of the colour produced with sodium acetate and sulfosalicylic acid. The recorded results show that the method has a maximum error less than 1%.

Potassium Periodate. A colorimetric micro method for the determination of sodium with manganese uranyl acetate was introduced by Woelfel.[18] The method describes the precipitation of 0·1 to 0·5 mg. of sodium from urine or the solution of the ash of blood serum as sodium manganese uranyl acetate. The precipitate is dissolved, the manganese oxidised to permanganate with potassium periodate and the colour compared with standard permanganate solutions.

Leva[19] further developed the periodate method and determined 0·008 to 0·01 mg. of sodium photoelectrically with an accuracy of ± 8%.

Leva's method has been modified recently by Shawarbi and Pollard[20] whose method is suitable for the determination of amounts of sodium ranging from less than 50 to 500 micrograms. A solution of alcoholic manganous uranyl acetate is used as the precipitant and filtration is followed by solution of the precipitate in dilute sulphuric acid. Traces of alcohol are removed by boiling and the solution is treated with potassium periodate. Maximum colour intensity is developed after boiling for a few minutes, and the colour of the cooled solution is measured in a tintometer.

Ammonium Carbonate and Hydrogen Peroxide. Arnold and Pray[21] have developed a spectrophotometric method for the determination of sodium which consists in precipitation of the sodium with either zinc uranyl acetate or magnesium uranyl acetate and measuring the transmission range of the orange to red solution of the salt in hydrogen peroxide and ammonium carbonate. The colour is reported to be stable for the period of determination and the sodium content is ascertained by reference to a transmission curve obtained with a series of solutions containing known amounts of sodium.

Centrifugal Estimation

Caley, Brown and Price[22] have presented a rapid centrifugal method for the determination of small amounts of sodium. Under correct conditions it is possible to obtain minute uniform particles which are readily reproducible. The determination is conducted throughout in Goetz tubes graduated at 0·01cc. intervals. Alcoholic magnesium uranyl acetate is used in preference to the aqueous reagents since only approximate temperature control of 4° to 5° C. is required. The precipitant is placed in the cone and is followed by the unknown solution containing not more than 2 mg. of sodium. Immediate mixing is necessary and the solution is stirred with a mechanical stirrer for ten minutes. The precipitate is then compacted under centrifugal force and its volume read. The quantity of sodium present in the sample may then be calculated since 1 mg. of sodium occupies an average volume of 0·078 cc. The method is subject to an error of 5% for amounts of sodium up to 2·5 mg. The authors have used their method for determinations of sodium in water and in milk and report satisfactory results.

Polarographic Estimation

A polarographic method for the micro determination of sodium in biological fluids has been advanced by Carruthers.[23] Sodium is precipitated as the triple salt with zinc uranyl acetate and the solution of the salt in dilute hydrochloric acid is polarographed. The diffusion current was found to be proportional to the concentration over the range 0·1625 to 0·975 millimolar. (0·1625 = 3·47 micrograms of sodium per ml.) Urech and Sulzberger[24] determine sodium in aluminium polarographically.

Caesium Bismuth Nitrite (Ball's Reagent).

Caesium bismuth nitrite has been successfully employed in the colorimetric determination of sodium. Doisy and Bell [25] dissolve the precipitated sodium caesium bismuth nitrite in an alkaline tartrate mixture and treat an aliquot portion corresponding to about 0·01 mg. of sodium with sulphanilic acid and α—naphthylamine. The bright red colour developed from the nitrite present is compared with standard solutions containing known amounts of sodium and treated exactly as the sample. The average error is about 5%.

An alternative procedure is that presented in the method of Tschopp.[26] The precipitate is dissolved in dilute nitric acid and the bismuth from the compound in solution is estimated as the colloidal sulphide.

Potassium Dihydrogen Antimonate (Fremy's Reagent)

Sodium may be determined indirectly by precipitating the metal with potassium dihydrogen antimonate and measuring the antimony in the solution of the compound as the orange collodial sulphide.[27]

By modification of the Kramer-Gittleman method, Rourke[28] was able to determine sodium in serum or plasma without removal of proteins, on either ashed or unashed samples. Precipitation was carried out on as little as 0·3 mg. of plasma or serum and the determination completed iodometrically.

Dihydroxytartaric Acid

The use of potassium dihydroxytartrate as a reagent for precipitating sodium in water on the macro scale was investigated by Radjy and Wood.[29] Vanadium pentoxide is recommended as an excellent catalyst for promoting the normal oxidation of dihydroxytartaric acid or its sodium salt with either potassium permanganate or ceric sulphate. The procedure adopted consists in treatment of the precipitate with an excess of the

15 McCance, R. A., and Shipp, H. L., *Biochem. J.*, 1931, **25**, 449.
16 Salit, P. W., *J. Biol. Chem.*, 1932, **96**, 659.
17 Darnall, M. C., and Walker, B. S., *Ind. Eng. Chem., An. Ed.*, 1940, **12**, 242.
18 Woelfel, W. C., *J. Biol. Chem.*, 1938, **125**, 219.
19 Leva, E., *J. Biol. Chem.*, 1940, **132**, 487.
20 Shawarbi, M. Y., and Pollard, A. G., *J. Soc. Chem. Ind.*, 1943, **62**, 71.
21 Arnold, E. A., and Pray, A. R., *Ind. Eng. Chem., An. Ed.*, 1943, **15**, 294.
22 Caley, E. R., Brown, C. T., and Price, H. P., *ibid.*, 1934, **6**, 202.
23 Carruthers, C., *ibid.*, 1943, **15**, 70.
24 Urech and Sulzberger, *Helv. Chim. Acta.*, 1944, **27**, 1074.
25 Doisy, E. A., and Bell, R. D., *J. Biol. Chem.*, 1920, **45**, 313.
26 Tschopp, E., *Helv. Chim. Acta.*, 1925, **8**, 893.
27 Yoshimatsu, S., Tohoku *J. Exptl. Med.*, 1927, **8**, 496.
28 Rourke, D. M., *J. Biol. Chem.*, 1928, **78**, 337.

oxidising agent in the presence of sulphuric acid, phosphoric acid and ammonium metavanadate. The amount of excess oxidising agent remaining is then determined by any one of the standard methods. Little attention has been devoted to the application of this reagent on the micro scale since it does not compare very favourably with the precision of the uranyl acetates. It may be possible, however, that measurement of the absorption of a standard potassium permanganate solution both before and after treatment with the sodium dihydroxytrate precipitate would provide a rapid and accurate method.

Other Methods

Adair and Keys[30] describe a micro method for the determination of a base by electrodialysis suitable for samples containing a total base equivalent to 0·2 mg. of sodium. The method is essentially a modification of the one devised by Stoddard which was designed for the joint determination of sodium and potassium and thus of sodium by difference if potassium is determined. An aliquot portion of the solution is electrolysed and the amalgam which is subsequently formed is removed and titrated. An accuracy of 2% is claimed.

Hegedüs[31] has modified the macro method of Szebellédy and Schick[32] for application on the micro and semi-micro scale. The solution of the mixed alkali sulphates or chlorides is converted into iodides by evaporation with hydriodic acid. Sodium is selectively extracted from the residue with a mixture of *iso*-butyl alcohol and ether saturated with potassium iodide. Separation of the extracted sodium and the insoluble potassium iodide is effected by filtration, and the determination of the two elements is completed by estimating the iodine in each fraction.

A polarographic method for the determination of sodium, potassium and lithium is due to Zlotowski and Kolthoff.[33] They specify the conditions under which sodium and potassium may be determined with an accuracy of 3% in a medium of 50% alcohol using tetraethyl ammonium hydroxide as the supporting electrolyte.

29 Radjy, A. H. K., and Wood, C. E., *J. Pet. Tech.*, 1933, **19**, No. 120, 845.
30 Adair, G. S., and Keys, A. B., *J. Physiol.*, 1934, **81**, 162.
31 Hegedüs, M., *Z. anal. Chem.*, 1936, **107**, 166.
32 Szebellédy and Schick, *Analyst*, 1934, **59**, 502.
33 Zlotowski, I., and Kolthoff, I. M., *Ind. Eng. Chem., An. Ed.*, 1942, **14**, 473.

Miscellaneous Microchemical Devices

By J. T. Stock and M. A. Fill

V. A Semi-Micro Test-Tube Stand

BEING of skeleton design and of all-glass construction, the device completely eliminates difficulty of viewing

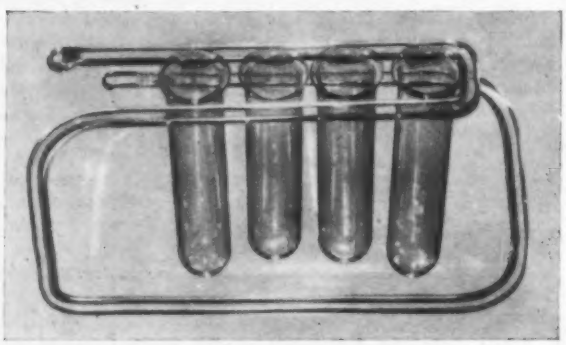

Fig. 1.—A Semi-Micro Test Tube Stand.

associated with wooden stands. The stand may be placed upon any suitable background, such as a sheet of opal glass or a piece of black paper, thus enabling tests to be observed under the optimum conditions.

The construction of the stand from a single length of 3 mm. glass rod, as shown in Fig. 1, is self-evident. As described, it accommodates six 50 mm. × 8 mm. micro test tubes; obviously, other sizes could be used by suitable alteration in dimensions. The tubes are supported by their flanged rims between the parallel rails, which are 9 mm. apart. This distance between the rails was found to give adequate support while permitting easy manipulation of the tubes. Individual tubes may be removed from the stand by placing the forefinger and thumb of one hand on opposite sides of the row of tubes, then lifting the desired tube near its bottom. Removal with the other hand is then simple. To prevent entry of dust, the mouths of the whole set of tubes may be conveniently covered with a microscope slide.

Owing to its compact nature and glass construction, the stand complete with tubes may be placed in a bath maintained at any desired temperature. In this connection, we have found it to be very useful in the preparation of osazones and similar derivatives of organic materials. Similarly, the whole unit may be dried by placing in a steam or air oven.

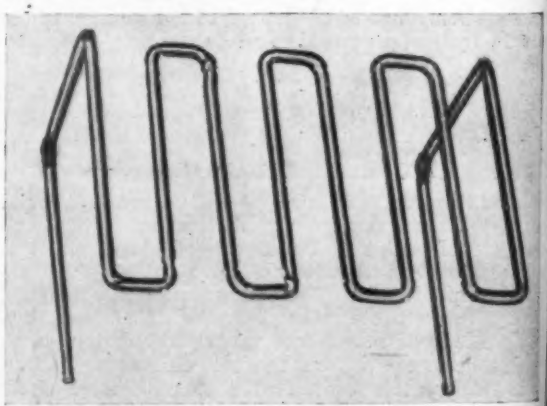

Fig. 2.—Stand with Multiple Bars.

For drying or for routine tests involving the use of a considerable number of tubes, the stand with multiple bars shown in Fig. 2 is useful.

METALLURGICAL DIGEST

Creep Properties of Some Binary Solid Solutions of Ferrite

By C. R. Austin, C. R. St. John and R. W. Lindsay

MANY of the factors influencing the creep behaviour of ferrous alloys have been investigated, including such variables as grain size, steel-making practice, nature and stability of the microstructure and the effect of alloying elements in steels. With respect to the latter the microstructures involved are usually heterogenous and as a result the effect of the addition is related to its effect on the various phases present in the microstructure. In the instances where this structure consists of ferrite and carbide, the behaviour of the alloy addition will be related to its action in strengthening ferrite and in opposing temperature softening of ferrite as well as coalescence of carbide. The results are therefore investigated of isolating one microstructural phase, namely ferrite, and studying its creep characteristics in both the unalloyed and alloyed conditions.

The iron binary alloys investigated were ferritic solid solutions of six of the more important alloying elements, namely chromium, molybdenum, silicon, manganese, nickel and cobalt. These alloys were prepared from hydrogen-annealed electrolytic iron by induction melting under an atmosphere of hydrogen. Ingots were forged to 2 in. square sections and rolled to ⅜ in. bars. All the alloys were given an annealing treatment in vacuum at 975° C. to relieve stresses.

Tests were carried out in a furnace having a uniform heat distribution and holding six test specimens and a standard. Spring loading of specimens was adopted, the load being applied by means of a lever system. Changes in length were read on a gauge and were estimated to the nearest 0·00001 in. In testing an initial load of 5,000 lb./sq. in. was applied to the test specimens for 600–700 hours, during which time the time versus extension relationships were established. The load was then stepped up to 7,500 lb./sq. in. and again held for 600–700 hours. Such loading was continued in 2,500 lb./sq. in. increments until either the specimen failed or had deformed to such a degree that further loading would be useless. The creep behaviour of the various alloys was investigated most completely at 425° C. but sufficient work was carried out at 540° C. to establish the significance of temperature. Creep-rate data for all the alloys tested at 425° C. and for all the alloys at 540° C. are given in Tables I and II, respectively.

The results obtained show that commercially pure ferrite possesses a relatively low creep resistance at 425° C. While nickel and silicon in solid solution raise the tensile strength and hardness of ferrite at room temperature, these elements have only minor effects on raising the resistance to deformation at elevated temperatures. Cobalt is similarly effective in raising the creep strength of ferrite but normal temperature tensile strength and hardness of cobalt solid solutions are not markedly different from the values for unalloyed iron. Chromium does not markedly influence the strength of ferrite at ordinary temperatures but definitely increases the creep strength of ferrite by its presence in solid solution. Manganese and molybdenum in solid solution are ferrite strengtheners and also increase the creep resistance of ferrite, molybdenum having an especially pronounced effect in this latter respect.

When the testing temperature is increased to 540° C. it is found that molybdenum raises the softening temperature of the cold-worked ferrite solid solution well above this temperature. The molybdenum alloys with 0·54 and 1·5% of molybdenum in solid solution are the only ones to retain any measure of creep resistance at this higher temperature. Although chromium and manganese are also effective in raising the softening temperature, they are not nearly so effective as molybdenum in strengthening ferrite at 540° C. Molybdenum, however, promotes solid solution hardening to a greater degree than either chromium or manganese.

The effects of the addition of 0·23, 0·53 and 0·91% of carbon on the creep characteristics of ferrite were also investigated. From the results give.

From *Metals Technology*, 1945, Vol. 12, No. 5, and A.I.M.M.E. Technical Publication, No. 1837, pp. 1–22.

TABLE I.—CREEP-RATE DATA FOR ALL ALLOYS TESTED AT 425° C. (% PER 1,000 HRS.)

Load Lb./sq. in.	Iron	Iron and Carbon			Iron and Cobalt			Iron and Chromium			Iron and Manganese			Iron and Molybdenum			Iron and Nickel			Iron and Silicon		
		0·23 C.	0·53 C.	0·91 C.	0·52 Co	1·00 Co	5·08 Co	0·45 Cr	0·99 Cr	4·83 Cr	0·69 Mn	1·33 Mn	7·25 Mn	0·11 Mo	0·54 Mo	1·50 Mo	0·57 Ni	1·15 Ni	4·83 Ni	0·22 Si	0·59 Si	1·21 Si
5,000	0·08	<0·01	0·02	0·03	0·11	0·12	0·03	0·02	<0·01	<0·01	0·01	<0·01	0·17	<0·01	<0·01	<0·01	0·05	0·05	0·09	<0·01	0·04	<0·01
7,500	4·54	0·34	0·08	0·07	2·32	2·16	0·10	0·02	0·01	0·02	0·03	<0·01	0·18	0·04	<0·01	<0·01	1·64	0·91	0·20	1·35	0·08	0·01
10,000	62·0	2·16	0·36	0·16	31·16	11·0	0·42	0·01	0·02	0·07	0·08	0·02	0·20	0·06	0·01	<0·01	20·0	11·31	0·74	12·73	0·41	0·20
12,500	700·0	46·77	5·0	1·13			10·72	0·05	0·08	0·05	0·20	0·02	0·29	0·16	<0·01	<0·01		86·4	5·02		1·50	11·25
15,000								0·13	0·08	0·07	0·32	0·09	0·35	0·23	0·01	0·02					3·55	
17,500								0·29	0·18	0·07	0·54	0·14	0·45	0·80	0·06	0·01					9·10	
20,000								2·24	0·44	0·21	1·06	0·30	0·57	2·10	0·09	0·03					93·00	
22,500									2·56			0·78		4·00	0·13	0·03						
25,000										0·27	2·08	1·66	0·89		0·18	0·04						
37,500													10·35			0·06						
50,000																0·49						
60,000																0·81						

TABLE II.—CREEP-RATE DATA FOR ALL ALLOYS TESTED AT 540° C. (% PER 1,000 HRS.)

Load Lb./sq. in.	Iron	Iron and Carbon			Iron and Cobalt			Iron and Chromium			Iron and Manganese			Iron and Molybdenum			Iron and Nickel			Iron and Silicon		
		0·23 C.	0·83 C.	0·91 C.	0·52 Co	1·00 Co	5·08 Co	0·45 Cr	0·99 Cr	4·83 Cr	0·69 Mn	1·53 Mn	7·25 Mn	0·11 Mo	0·54 Mo	1·50 Mo	0·57 Ni	1·15 Ni	4·83 Ni	0·22 Si	0·59 Si	1·21 Si
5,000	4·30	9·85	2·14	1·83			6·75	0·04	0·09	1·16	1·81	0·61	1·03	2·43	0·05	0·05			8·76		3·00	12·16
7,500			10·4	8·32				4·43	16·5	4·42		3·45	1·20		<0·01	0·01						
10,000													3·96									
12,500															0·05	0·01						
17,500															0·34	0·14						
20,000															2·88	0·69						
22,500																5·14						

in Tables I and II it is seen that increasing the amount of carbon progressively increases the creep strength at 425° C., but the increase in creep resistance produced by the presence of the carbide phase in lamellar distribution does not equal that produced by chromium, manganese or molybdenum in solid solution. When these iron-carbon alloys were tested at 540° C., their creep resistance was little greater than that of single-phase ferrite and they were structurally unstable, and showed a definite tendency to spheroidise.

Influence of Various Elements on Copper

TWO researches have been published recently, dealing with the influence of various elements on copper. In the first,[1] the solubility of carbon in molten copper was studied, and in the second[2] experiments on the effect of phosphorus, arsenic, sulphur and selenium on the properties of high-purity copper were described. In the first investigation M. B. Bever and C. F. Floe carried out a series of experiments by preparing copper samples saturated with carbon at various temperatures and then analysing these samples for carbon by a modified vacuum-fusion method. As the solubility of carbon in liquid copper is small and decreases on cooling and solidification, the samples had to be prepared by rapid quenching from the saturation temperatures. Quenching methods employed were gas quenching in purified nitrogen and a modified water quench in which the metal remained under a protective atmosphere of purified nitrogen. Samples were also made by continuous casting. Saturation temperatures for the quenched samples varied from 600°–950° C. and for continuous casting from 590°–980° C. Special high-purity copper was used for all the samples.

The method by which the copper samples were analysed for carbon was based on the oxidation of carbon to carbon monoxide or dioxide and a quantitative determination of these gases, and the technique for carrying out this method was by vacuum-fusion. In principle, the method consisted of introducing the sample under vacuum into a copper bath that had a fairly high oxygen concentration. As the sample fused into the bath any carbon present formed gaseous oxides and these gases were removed, together with any other gases that might be evolved and analysed.

The results obtained showed that the solubility of carbon in molten copper to vary from about 0·0001% at 1,100° C. to 0·003% at 1,700° C. Carbon dissolved even in these very small amounts can be one of the major causes of gas porosity in copper and copper-base alloys. At 1,200° C. the equilibrium solubility in 100 grams of copper was sufficient to form about 0·25 cc. of carbon monoxide or dioxide if all the carbon became oxidised. This was equivalent to more than one cubic centimetre at the freezing point of copper and while this was a considerably smaller gas volume than the hydrogen solubility at the same temperature, an important difference lay in the fact that the carbon oxide gases were practically insoluble and therefore were evolved as fast as they were formed by oxidation of the dissolved carbon. Preliminary work on the solubility of carbon in tin bronzes showed values approximately the same as those for pure copper, so that the conclusions formed for copper are in general applicable to bronzes.

In the second investigation, data were presented by J. S. Smart and A. A. Smith, directed towards a better understanding of the basic behaviour of phosphorus, arsenic, sulphur and selenium in copper, with particular emphasis on the composition range 0–0·05%. Such data were a part of a general programme of research on the effects of impurities on the properties of oxygen-bearing and oxygen-free copper. The behaviour of the individual elements was determined from measurements of conductivity at 300°, 400°, 500°, 600°, 700° and 800° C. and by softening temperature measurements.

The binary alloys used whose compositions as regards the various elements are given in Table I, were synthesised from high-purity copper in order to eliminate interference from the effects of extraneous impurities. Alloys of selected composition were first prepared in the oxygen-free form by continuously casting the melts in the form of $\frac{3}{8}$ in. rod. Oxygen was added subsequently to portions of the alloys, either by remelting or by diffusion at 850° C. from a surface scale. Test wires were drawn using four 30 min. 600° C. annealings at 0·3125, 0·257, 0·204 and 0·162 in., and a final cold reduction of 75% to 0·081 in. Oxygen-bearing slugs made by remelting were hot-rolled to $\frac{5}{16}$ in., drawn to 0·162 in., annealed for 30 min. at 600° C. and cold-drawn 75% to 0·081 in.

TABLE I.—COMPOSITION OF ALLOYS

Phosphorus	Arsenic	Sulphur	Selenium
Nil	Nil	Nil	Nil
0·0002	0·0006	0·0003	0·0005
0·0008	0·0015	0·0008	0·0010
0·0011	0·0046	0·0015	0·0050
0·0059	0·0090	0·0050	0·0100
0·0200	0·0465	0·0100	0·0300

The results obtained showed that phosphorus entered the solid solution in oxygen-free copper, resulting in major losses of conductivity and increases in softening temperatures. Up to 0·0059% phosphorus the unit loss of conductivity was 0·73% for each 0·001% phosphorus added. Phosphorus and oxygen combined quantitatively to form an insoluble oxide. Arsenic in amounts up to 0·05% did not combine with oxygen and therefore was effective in both

1 *Metals Technology*, 1945, Vol. 12, No. 6, A.I.M.M.E. Technical Publication No. 1802, pp. 1–14.

2 *Metals Technology*, 1945, Vol. 12, No. 6, A.I.M.M.E. Technical Publication No. 1807, pp. 1–12.

oxygen-free and tough-pitch coppers. Arsenic lowered the conductivity linerly 0·33% per unit with 0·001% arsenic added within the composition range 0–0·01% arsenic. The softening temperature increased moderately within these limits.

The solid solubility of sulphur in copper increased from approximately 0·0002% sulphur at 600° C. to around 0·002% at 800° C. The unit effect of sulphur was high, but the total effects were curtailed by its limited solubility. Sulphur and oxygen did not combine to form an insoluble precipitate. The solid solubilities of sulphur and selenium appeared to be of equal magnitude at 500° C. but that of selenium increased at a much faster rate with increasing temperature, and approached 0·015% at 800° C. Selenium also did not combine with oxygen in the composition ranges investigated, and significant increases in softening temperature could be obtained from heat-teatments that retained the soluble form. The losses of conductivity with this element were moderate.

A Relationship Between Hardenability and Tensile Strength of Normalised Steels

By L. A. Carapella

THAT the hardness and tensile properties of steels are related has long been common knowledge to the physical metallurgist. Of similar recognition is the fact that the hardness of steels is more or less governed by the hardenability, depending, of course, on the rate of cooling from the austenising temperature. On the basis of these existing evidences, a relationship between hardenability and tensile properties is suggested, and the underlying reason in support of this suggestion is that the inherent factors of hardenability—*i.e.*, chemical composition and grain size, fundamentally influence the eutectoid compositions, transformation temperatures and rates of reaction, and thereby alter the general character of the aggregate structures of the steels.

In the development of the equation correlating hardenability and normalised tensile strength, three independent relationships have been used, namely :

(*a*) Hardenability as a function of the ratio of hardness in both the water-quenched and normalised conditions.

(*b*) Water-quenched hardness as a function of carbon content.

(*c*) Hardness as a function of tensile strength.

Before arriving at the final equation, it was found necessary to derive within certain limits, selected so as to include conditions likely to be experienced in commercial practices, suitable mathematical expressions for each of these functions.

Of the many investigations carried out on both the hardness and hardenability of steels, the work of Field[1] is of noteworthy importance because it shows a quantitative correlation between the ideal critical diameter (hardenability) and the ratio of initial-end-hardness to the distance hardness of a Jominy test bar. A further consideration of this work reveals that the general function :—

$$\frac{H'}{H} = A \log_e D_1 + B \qquad (1)$$

where H' = the initial hardness, H = the distance hardness, D_1 = the ideal critical diameter and A and B = constants, defines the relation of hardenability to hardness ratio, and that the function is valid over a wide range of cooling rates. As a general case, H' may be assumed as the water-quenched hardness and H as the hardness which results from a particular rate of cooling from the austenising temperature.

TABLE I.—HARDENABILITY AND NORMALISED TENSILE STRENGTH OF SOME EXPERIMENTAL STEELS.

No.	Carbon %	D_1 (Obs)	T.S. (Obs)
E 1	0·25	0·55	70,850
E 2	0·30	0·75	76,700
E 3	0·36	1·03	89,500
E 4	0·35	1·55	90,100
E 5	0·20	1·76	83,400
E 6	0·40	1·80	93,500
E 7	0·50	1·85	120,000
E 8	0·28	1·97	93,000
E 9	0·43	2·19	116,000
E 10	0·31	2·37	107,000
E 11	0·29	2·40	95,000
E 12	0·32	2·40	102,000
E 13	0·38	2·40	108,000
E 14	0·35	2·53	105,000
E 15	0·40	2·65	120,000
E 16	0·33	3·10	119,000
E 17	0·40	3·20	126,500
E 18	0·27	3·90	119,000
E 19	0·27	3·94	129,000
E 20	0·39	4·18	134,000
E 21	0·41	4·80	150,000
E 22	0·33	4·85	130,000
E 23	0·28	5·50	145,000
E 24	0·26	5·50	158,000
E 25 ..	0·31	5·80	162,000

For plain carbon and common alloy steels, other investigators have demonstrated that the maximum hardness attainable upon quenching depends on the carbon content alone and is independent of the austenitic grain size. From general experience, however, the hardness of water-quenched steels has been found to fall within certain limits and the equation :—

$$H' = 300 \log_e \% \text{ Carbon} + 780 \qquad (2)$$

where H' = the water-quenched hardness (B.H.N.) gives the most probable value of hardness. The validity of hardness as a function of tensile strength has been established over a wide range of hardness and tensile strength for plain carbon and alloys steels, but only that range of hardness and tensile strength generally found in normalised steels has been considered for the equation :—

$$\text{T.S.} = 465\ H + 5{,}000 \qquad (3)$$

where T.S. = the tensile strength in lbs./sq. in. and H = the hardness (B.H.N.).

By combining equations (1), (2) and (3), a general empirical expression relating to hardenability and tensile strength for any rate of cooling from the austenitising temperature has been obtained and is stated as :—

$$\text{T.S.} = \frac{93{,}000 \log_e \% \text{ Carbon} + 362{,}700}{A \log_e D_1 + B} + 5{,}000 \qquad (4)$$

The constants A and B define the rate of cooling after an austenitising treatment, and once these constants are determined for a particular rate of cooling, the tensile strength can then be computed from the hardenability of a steel subjected to this type of treatment. In order to determine the constants, A and B, for steels given a commercial normalising heat-treatment, the data given in Table I, representing a wide range of carbon contents and hardenability values, were used. The constants were established by applying the method of least square to equation (4) and the data given in Table I. Accordingly, the tensile strength of normalised steels and hardenability have been found to be related as follows :—

$$\text{T.S.} = \frac{93{,}000 \log_e \% \text{ Carbon} + 362{,}700}{-0{\cdot}85 \log_e D_1 + 3{\cdot}25} + 5{,}000 \qquad (5)$$

The calculated normalised tensile strength values agree fairly well with those observed for a large number of normalised silicon-manganese steels, for a variety of commercial normalised steels made by various steel-making processes and also for structural steels. The variation is rarely more than ± 10; in the majority of cases, it is less than ± 5% of the normal expectancy value.

From *Trans. Amer. Soc. for Metals*, 1945, Vol. 35, pp. 435–445.

1 J. Field, *Metal Progress*, 1943, Vol. 43, p. 402.

A Protective Finish for Magnesium Alloys

By R. B. Mason

THE coatings which are formed on magnesium alloys by certain electrolytic treatments are thicker and considerably more resistant to abrasion than coatings that are formed by simple chemical treatment. Further, the resistance of these oxide coatings to corrosion can be improved appreciably by the use of a final sealing treatment. For magnesium and magnesium alloys, therefore, coatings of this character are of considerable advantage where resistance to both abrasion and corrosion is essential.

When magnesium is made the anode in a sodium hydroxide electrolyte, little current will flow at ordinary temperatures. Heating the electrolyte however, causes a satisfactory current to flow at a relatively low voltage. The coating formed has a slightly alkaline reaction, is somewhat soluble in water and is larger in volume than the volume of metal from which it is formed. The coating is considered to be essentially magnesium oxide, but it may be somewhat hydrated.

In the anodic treatment, of magnesium alloys, the condition of the surface of the article being treated has considerable influence on the voltage requirements and the resulting coating. The throwing power of the sodium hydroxide electrolyte is much less than that of the sulphuric acid electrolyte used for the Alumilite treatment of aluminium alloys. Consequently it is essential to have the surface of the magnesium alloy as clean as possible. Special cleaning procedures are necessary to accomplish this.

Ordinarily, most of the grease can be removed by treatment in a nearly boiling 5–10% sodium hydroxide solution or in a solution containing sodium carbonate and tri-sodium phosphate. Following degreasing, an additional treatment of some type should be used to remove heavy oxide films. This is usually accomplished by immersion in a chromic acid solution. If the oxide coating is to be subsequently dyed, however, a 2 min. etching treatment in a 20 pct. ammonium chloride solution, at room temperature may be employed instead of the chromic acid solution. For magnesium castings that have not been machined, it may be desirable to use a nitric acid-sulphuric acid solution, to remove some of the surface skin rapidly before using either the chromic acid solution or the ammonium chloride etch.

The articles, after being thoroughly cleaned by the procedures described above, are connected as an anode in an electrolyte containing a 5% sodium hydroxide and are treated for a period of 30 min. with a current density of 12–18 amp./sq. ft. Ordinarily, a potential of 4–5 v. will be sufficient when the temperature of the electrolyte is between 140° and 160° F.

After the electrolytic treatment, the coated article should be washed thoroughly in water and then sealed for 30 min. in a sodium chromate solution which is maintained at a temperature of 170°–180° F. Dichromates are not suitable for use in this sealing treatment since the magnesium oxide coating will be dissolved or disintegrated by an acid solution. Following the sealing treatment, the oxide coatings have a lightly yellowish colour and are relatively smooth and hard. These coatings provide good protection against abrasive and corrosive action and serve very satisfactorily as a base for painting.

From *Iron Age*, 1946, **157**, pp. 48–52.

Materials for Internal Combustion Engine Valves

By H. Cornelius

ONE of the most stressed parts, both mechanically and thermally, of an internal combustion engine is the outlet valve, especially in modern aeroplanes. The inlet valve operates under much cooler temperature. The material used for valves must possess good machinability, fluidity in casting, and also good weldability.

The heat-resisting materials for the outlet valve are now mostly cooled by making the valve shaft hollow, and sometimes also the valve disc, for enclosing sodium as cooling agent.

The motion of the moving hot valve throws the molten sodium to and fro and so conducts the interior heat to the valve shaft. Sodium proved superior to all other substances, because of its low melting point, moderate vapour pressure at high temperatures, high heat conductivity, and low density. This made possible a reduction of the maximum temperature of the outlet valves up to 150° C.

Head and shaft of the valve are made of different materials, each best suited for the part. An austenitic steel is used first as carrier of the heat resistance on the shaft and on this is then welded a layer of hardenable steel or a hard alloy. Hardnesses of 500 to more than 600 Vickers are attained.

The gliding part of the valve stem is improved by cold-deformation or nitriding. The valve disc is improved on the seat by welding on a layer of a hard alloy of 1·2 to 1·5 carbon, 25 to 27 chromium, 60 to 65 cobalt, and 3 to 6% tungsten. The hardness attained is about 450 Vickers.

Lately, a somewhat softer alloy (Brightray) of 0·5 carbon, 1 manganese, 0·3 silicon, 20 chromium, 74% nickel, remainder Fe, with a hardness of 250 to 300 Vickers units, has been recommended. The bottom of the disc is protected either by a layer of Brightray or by a chromium-cobalt-tungsten hard alloy with a hardness at the seat of 485 and at the bottom of 420 Vickers units.

Of hardenable steels with conversion temperatures above the operating temperatures of the valves, the following had practical importance: Nickel-chromium steels (0·12 to 0·35 carbon, 0·3 to 1·5 chromium, 3·5 to 5% nickel), high-speed steels, silicon-chromium steels (0·4 carbon, 4 silicon, 3% chromium) rust-proof chromium steels (0·4 to 1·5 carbon, 9 to 16% chromium) with or without additions of silicon, cobalt, tungsten, molybdenum or vanadium, singly or almost all together. Their disadvantage is reduction of mechanical strength at higher temperatures. Austenitic steels are superior in this respect. Those used are 0·2 to 1·2 carbon, 0·2 to 3·5 silicon, 0·4 to 1·5 manganese, 11 to 25 chromium, 7 to 62 nickel and 0 to 5% tungsten, with occasional additions of molybdenum, cobalt and also vanadium.

As materials for the seat rings austenitic cast iron (3·0 to 3·4 carbon, 2·0 to 3·0 silicon, 10 to 12 manganese, 5 to 6% nickel), quenched from 1,000° C. (1,830° F.) and tempered at 500° C. (930° F.), with a Brinell hardness of 220 to 280 is used, as are aluminium-nickel-iron bronze and manganese-chromium steels.

From *Stahl u. Eisen*, Vol. 64, July 6, 1944, pp. 433–438; July 13, 1944, pp. 453–458.